

Simplified Curve and Switch Work

By

W. F. RENCH

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Charles Schnatterbeck

L I B R A R Y



PRESENTED BY

Charles Schnatterbeck

Simplified Curve and Switch Work

A Collection of Valuable Points
for the Supervisor and Foreman
and for College Instruction.

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BY
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Supervisor, Pennsylvania Railroad

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TO
MR. ELMER T. HOWSON
Civil Engineering Editor of the Railway Age Gazette
whose counsel and criticism
have been of much help.

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with his kind permission,
respectfully inscribed
by the author

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FOREWORD.

This work, as the title indicates, is a simplification of methods for solving curve and switch problems. The principal object has been to reduce the solutions to their simple arithmetical relations, so that the large majority of track men may have at their command a means of meeting such questions.

The method of "throw and resultant" for realining curves has been in use on a number of railroads for a period of about twenty years. The supplementary rule announced in this book, wherein is contained the relation of error to correction and by which the proper throw may at once be ascertained, will effect a large saving of time and labor in the lining of curves by that method. The "diagnosis" of the curve must be left for the investigator, although certain suggestions are made that will prove helpful, and the examples selected illustrate not only typical cases but some that are unusual.

The placing of a speed limit upon all train movements has rendered the determination of the proper superelevation a matter of simple calculation by a safe empirical rule. This plan will save greatly in maintenance by avoiding the experimenting that the engineer or supervisor knows is the method usually employed. The rule given in this book has been fully tested in the most widely varied service, and is offered with the fullest confidence in its usefulness.

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The addition of an easement to all curves operated at high speed, and to the sharper curves used at moderate speed, is now considered not merely a refinement, but an essential feature in the adjustment of the line. The curve that is generally accepted as the ideal easement is the *cubic parabola*. The easy method advanced herein for locating this curve by the instrument should appeal to engineers as requiring no reference data of any kind and only the simplest of calculations. The method by middle ordinates should appeal to the track man as supplying a ready means both for applying and maintaining the curve in string lining.

The rules for switch connections are intended to eliminate all need for tables or pocket memoranda, and are designed to make possible the solution of such problems by the more intelligent track foremen. The importance of the latter feature cannot but appeal to maintenance officers, as tending to render the track foreman's position a more attractive one.

No apology is thought necessary for the introduction of matter pertaining to narrow-gage switch work, since one-sixth of the total railroad mileage of the world is of less gage than the standard, and a widening interest centers in the industrial development of South America where the narrow gage predominates.

The examples in siding layout are those which are of every day occurrence, and the aim has been to confine the solutions to the simpler theorems of

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geometry, developing formulae that enable the location to be made with appliances which are always at hand.

Neither in the item of switch installation, nor in that of siding location, is the work intended to replace the much more comprehensive field books, but rather to supply what these lack. The information given represents the sum total of what the engineer or supervisor needs to carry in his mind, and with patient study it may all be learned by the brighter track foremen.

To meet the acknowledged unequipment of most newly graduated engineers in the particular field of track maintenance, it seems desirable to impart a fuller and more detailed instruction in the practical elements of curve and switch work. The various field books deal only with the theoretical functions, and it is necessary for the young engineer in practice to adjust his knowledge to actual working conditions. This requires in most cases a long apprenticeship, in which each separate problem must be encountered and its correct solution determined by successive trials.

It is with a view of eliminating such experiments that this book, embodying the conclusions of a wide practical experience, has been designed. The author has been continuously engaged in maintenance work with the Pennsylvania for twenty-five years, and within that period has handled a number of times every problem referred to. It is confidently believed that the methods, rules and suggestions

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advanced will be found to represent the most recent and approved practice.

The book is therefore commended to the colleges as supplying profitable reading in the Civil Engineering courses, especially that of Railway Engineering, which, by reason of the heavier burden being laid upon our transportation system, is assuming an ever-increasing importance in the technical world.

INTRODUCTION.

The two subjects, curve and switch work, embrace elements which are mainly technical in character. They involve a certain amount of measuring and figuring, necessary to correctness in design, and they also include problems in execution, or the actual placing of the work. The only requisite of the tangent track is that it shall be straight and level; but the adjustment of curves, the installation of switches, and the laying out of industrial tracks, require the use of simple mathematics, as well as a knowledge of actual track work.

Both subjects have heretofore been developed principally for the engineer and almost wholly from the theoretical standpoint. A knowledge of the geometrical functions of curves is desirable, and an understanding of the physical principles of curvilinear motion quite useful; but the practical conditions on even the best railroads make it impossible to use rules founded upon theory alone. It is quite generally recognized that easements are necessary to curves, and must be secured in some way or other. The impracticability of employing superelevation directly proportional to the degree of curve is also fully appreciated.

The theory of turnouts is based upon the supposition that the switch and frog rails follow a regular curve, but this is seldom true in practice. While the stub switch, now a fast-disappearing

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feature in track construction, was the single type in use, and frogs were only a few feet in length, the difference in theory and practice was not great. But the present use of point switches as long as 30 ft. and frogs of a similar length, has made necessary a change in switch practice. When layouts were not extensive and physical features such as the undergrade bridge were few, leads could be made the true practical length. Now such structures frequently necessitate a departure from ideal design; and a knowledge of what measurements may be varied without disadvantage, and of the permissible extent of such variations, becomes quite essential.

The proper adjustment of curves has become a most important element in maintenance, because of the higher standard in track structure imposed by the heavier and faster traffic. The travel of today demands a smoothly-riding track, and the larger and stiffer equipment requires it, to insure the movement being not only safe but expeditious. Curves cannot be brought to or kept in smoothly-riding condition, even with the most faithful maintenance, unless the needed adjustments of the alinement and the superelevation are first made.

The correct spiraling of curves and the proper placing of the easement and run-off are of just as much importance as the lining of the main part of the curve. A knowledge of the practical elements in location and maintenance are necessary that past errors may be avoided, and efficient meth-

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ods established to attain a high standard and to maintain it.

The subject of switch work is especially important because of the increased length of the locomotive wheel base, and because trains must frequently be passed at high speed from one track to another, not only with safety but with comfort to the passenger. Correct design and construction are therefore of paramount importance. There are a number of rules, which it is important to know, and which may be remembered easily. They are generally exact, sometimes empirical, but should never be "rules of thumb."

The hints for layout given in this book embrace a number of special features which are likely to arise in actual work, and the practical considerations in installation, maintenance and operation of switch connections discuss important points. They are based upon the practice of several of the larger railway systems, and should be of use in solving problems of track work by methods which are known to be efficient.

Six problems in siding location are given which will be found convenient for cases of new siding layouts, and they may also be applied with equal facility to changes in main track alinement. Clearance, grade and curvature must be carefully considered in planning new sidings because of a persistent expansion in manufacturers, which is certain to greatly increase with the readjustment of industrial conditions throughout the world.

PART I—CURVES

CHAPTER I.

THE RELINING OF CURVES WITH A STRING.

1. DEFINITIONS OF CURVE FUNCTIONS.

Curve and Tangent—A few of the terms that are used in connection with curves should be understood as a necessary equipment for the study of curve adjustment or switch layout. The line of a railroad is made up of straight lines and curves. The straight lines are called tangents because they are placed tangent to the curve. The curve is considered as extending between the tangent points where it meets the adjoining straight lines.

P. C. and P. T.—The first tangent point, or the point where the curve may be regarded as commencing, is the point of curve, and is designated by the initials P. C. The second tangent point, or the point where the curve ends, is the point of tangent, and is designated by the initials P. T. These points are only relative and depend upon the direction the line is considered to take.

Simple Curve—A simple curve is a part of a circle joining two tangents. It is defined either by its radius, R , or its degree of curve, D . The degree of curve is the angle at the center subtended by a chord of 100 ft., the chord being a straight line joining two points on the curve. Degree of curve

is expressed in degrees and minutes, there being 60 min. in each degree. The foreman will better understand the degree as the number of inches measured between a curve and the middle of a 62 ft. string stretched along the curve.

Compound and Reversed Curves—A simple curve has been defined as part of a circle joining two tangents. When two or more circular curves are included between two successive tangents, the curve is known as a compound curve. When two or more curves turn in opposite directions the curve is called a reversed curve. If any tangent, no matter how short, occurs between two simple curves, they do not form a compound or reversed curve.

True P. C. and P. T.—The true P. C. and P. T. of a curve are seldom to be found at the actual ends of the curve. There is always some easement or spiral curvature at the ends of every operated curve. The middle of this will generally be close to the true P. C. and P. T. It is preferable to speak of the ends of the curve as "beginning of spiral" and "end of spiral," the direction in both cases being considered toward the middle of the curve. If correctly adjusted the point of no elevation would be the beginning of spiral and the point of full elevation somewhat beyond the end of spiral.

Curve Ordinate—The ordinate of a curve is the right angle distance between the chord and the curve. The middle ordinate is the one measured at the exact middle of the chord. The quarter ordi-

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nate, which is employed in switch work, is the offset at the points one-fourth the length of the chord from each end. In this work for the sake of brevity ordinate is always meant to be the middle ordinate, unless distinctly stated otherwise.

Mean Ordinate, Throw and Resultant—The “mean” ordinate of an entire curve, or of a selected group of ordinates, is the average of all the ordinates that are being considered at one time in any part of the curve adjustment. Ordinarily it represents the general curvature either of the whole curve or the part of the curve that is being studied. For greater convenience the amount of throwing done upon the curve is expressed by the simple word “throw.” It measures only the amount of the change at the several points, and has nothing to do with the throwing done between the several points. The points should properly be called “stations,” and they are so designated generally throughout this work. The word “resultant” is used for the middle ordinate that would be measured after any particular throw at an adjoining point. It is not necessary that the resulting ordinate be actually measured, and in fact this is practically never done. The term “half function of throw” is used in several places, and means the half corrections that affect the adjacent points after a throw at the point between them.

2. USE OF STRING METHOD.

Many roads require the alinement of curves to be maintained by using the string method. While

RELINING CURVES WITH A STRING

it is usually intended that this shall apply particularly to the minor corrections which may be called "detail lining," it will be found that this method is equally useful in restoring the general line, and is even superior in this respect to the engineer's instruments. The general realining of a curve, being an engineering problem, is not strictly within the scope of the track foreman's duties. It is even desirable that foremen who are not familiar with the manner of realining an entire curve, shall be prohibited from using the string for any other purpose than detail lining, or, at the most, for obtaining the data necessary to a study of the curve by the supervisor.

This method of lining takes advantage of the well-known fact that a curve which is maintained fairly well, but which lacks attention from the engineers for a time, is likely to become a succession of elliptical curves, each of short length, but some flatter and others sharper than the average of the curve. It is necessary that a regular curve be substituted for these, and the one should be applied which will require the least throwing of the track.

Experience has shown that this cannot, as a rule, be determined by the use of the engineer's instruments, and in any event, the string method is much less costly and is generally more accurate. This method has the further advantage that the means of performing the field work are always available, and no special mathematical knowledge is neces-

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sary for either the field work or the application of the corrections. The method is rendered especially easy by the rule stated in Article 7, so that the entire study and correction of a curve may be made by the brighter track foremen.

3. GEOMETRICAL PRINCIPLES.

Basis of Method for String Lining—The basis of the system of curve adjustment by means of a string is the geometrical principle, illustrated in Fig. 1, that a line joining the midpoint of the two sides of a triangle is equal to one-half the third side. By a study of the figure it will be seen that the string in the position AC, which it held when the ordinate at B was first measured, forms one side of the triangle. The position AC' or AC'', which the string would occupy if the amount of the ordinate at B were measured *after* an outward or inward throw at C, forms the second side. The effect of the throwing at C upon the ordinate at B, and of course upon that at D as well, would be equal to one-half the throw at C, which forms the third side of the triangle.

This method, while not absolutely exact, is sufficiently so for all practical purposes. The error is negligible for even the sharpest curve or the longest length of string. *When the effect of the throwing at one point upon the two adjacent points is understood, many foremen will realize why lining at successive points, so as to have for the moment the selected aver-*



CC' and CC'' = inward and outward throw CG and BF = middle ordinates. FF'' and FF''' = half functions of CC' and CC'' BF and BF'' = resultants at B . $C'G$ and $C''G$ = resultants at C .

Fig. 1. Showing Effect of Throwing Track at One Point Upon Adjacent Points.

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age ordinate, does not result in the correction of the defective line.

Referring again to the figure, the resultant at C, after an inward throw of the extent shown by CC', will plainly be the amount of the original ordinate with the entire throw deducted. The resultant at B will be the original ordinate at that point with one-half the throw made at C added, and the same will be true of the resultant at D. This correction, which may be called the "half-function of the throw," is equal to the line FF'. The resultant at C would thus become the line C'G, and at B the line BF'. On the other hand, if the curve were shifted outward at C to include the point C'', the ordinate at C would be increased by the full amount of the throw at that point, and the ordinates at B and D would be decreased by half the amount of this throw. The distance to be subtracted from the ordinate at B or D is shown in the figure as FF'', and the resultant at C is the line C''G, and at B is the line BF''.

General Rule for the Effect of Throwing—The general rule may now be stated and should be perfectly clear. Whenever the term "throw" is used in this work it will mean the distance that the curve is to be moved at any one point, and the term "resultant" will mean the ordinate that would result from a throw at an adjacent point. *The throwing of the curve at one point causes the ordinate at that point to increase or decrease by the full amount of the throw according as the throw is out-*

ward or inward; and also causes the ordinates of the two adjacent points to correspondingly decrease or increase by half the amount of the throw, the effect being an increase when the throw is inward and a decrease when the throw is outward. In exceptional cases, when the curve is badly out of line, the applied inward throw or half-function of outward throw may exceed the ordinate or resultant, when the smaller figure must be subtracted from the larger and a minus value be given the resultant. This means that such resultant must be subtracted where ordinarily it would be added in any succeeding process.

Five Operations in String Lining—The relining of a curve with a string consists of five successive steps, which are as follows: 1st, the preliminary test; 2d, the study of the locality; 3rd, the diagnosis; 4th, the solution; 5th, the application. All these steps are important, and should be conducted with care. Fine accuracy is not as essential as the avoidance of distinct errors. *The preliminary test* is made with a proper kind of string, which should be as thin as will withstand drawing entirely taut. The measurements should be taken with care and no misreading made, as one false ordinate will destroy the value of the adjustment, at least for the group in which it occurs.

The study of the locality is not only important as a safety measure to determine what can be done, but it shows to the practical eye of the expert foreman just what corrections appear to be necessary, although of course it would not determine their extent. The

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detailed study of the curve, which is called *the diagnosis*, bears the same relation to the curve adjustment that the physician's study of a case does to the art of healing. The *solution* is a practical means of determining with the least expense of time and labor the exact corrections necessary. *The application* gives some hints as to the most convenient manner of performing the actual work of lining the curve.

CHAPTER II.

PRELIMINARY STUDY OF THE CURVE.

4. THE TEST WITH A STRING.

It is desirable in all cases that slight defects in the line of the curve be corrected as far as possible by eye, before the string is used and the test ordinates measured. This will not only lighten the labor of the solution, but will facilitate the finding of the best solution.¹ (If this is not done beforehand, detailed adjustments may be made in the original notes with the object of establishing groups of ordinates that will form a practical solution. But then care would have to be taken to correct the resulting throws in accordance with the preliminary adjustment.)

Accuracy—The ordinates should be measured to the nearest one-eighth inch. In the solution, when taking half the throw to apply as a correction at the adjacent points, if the throw should be an odd number of eighths, as $\frac{3}{8}$ or $\frac{7}{8}$ in., it is proper to use the nearest one-eighth above or below as best suits the case. The engineer might prefer to employ decimals of a foot, and the nearest one-hundredth foot should then be used. It is generally found preferable to adopt inches, because the ordinates will nearly always be taken by the foreman, and the lining of the curve done later by him, and he can most easily make his measurements in inches.

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Length of String—The length of string may be 62 ft. for branch-line curves, and may vary between 62 ft. and 100 ft. for main-line curves. It is sometimes useful to fix the length of the string so that a station may occur at each full elevation point. Before the ordinates are measured, marks should be made entirely around the curve at points one-half the string length apart, these being consecutively numbered for future use. The stations should extend as far as there is any curvature, since it is equally important to have the easements or spirals in proper position.

Common Error—A common error of the inexperienced foreman is to take the ordinates by moving around the curve a full string length, instead of a half string length at a time. This, of course, renders the test of no use. While measuring the ordinates, notes should be made of the amount of the superelevation and the points where it begins and where the full elevation is reached; also of any obstructions which would prevent lining the track in either direction.

5. THE STUDY OF THE LOCALITY.

It is not only a distinct advantage, but desirable as a safety measure, that the supervisor or roadmaster, as well as the foreman, should observe conditions at the curve before the solution is finished, and preferably before it is begun; in other words, before the throws for the different stations have been figured out and finally determined upon. On

double- and multiple-track roads, especially those with track centers close to 12 ft., the leeway should be known so that the safety of the parallel movements will not be endangered by the lining. On many branch lines, particularly those that parallel river courses, the present clearances with rock bluffs are barely sufficient, and any encroachment by the subsequent shifting might be more or less dangerous. The physical features of the situation should be fully known, so that the necessary adjustments can be provided for.

Very many of the simpler cases of curve adjustment will be disposed of by the supervisor upon the occasion of his regular trips to the various points where his subdivision forces are engaged, and the attentive foreman will thus observe the direct application of the rules he has studied.

6. THE DIAGNOSIS OF THE CURVE.

Figuring the Mean Ordinates—The determination of the right treatment for a curve, which operation may be called the "diagnosis," is the most important part of the proceeding. The first step in this determination is to ascertain the mean or average ordinate for the body of the curve. Before this can be figured it is necessary to cut off the ordinates at the ends of the curve, which will plainly belong to the easements of the curve. The remaining ordinates, which constitute the body of the curve, are then carefully added together. The sum divided by the number of ordinates added

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will give the average or "mean" ordinate. If the whole number in each of the ordinates is the same, the fractions only need be considered. These may all be reduced to eighths, and their sum divided by the number of ordinates used will give the fraction to place after the uniform whole number to supply the mean ordinate.

Easement or Spiral—An easement or spiral must next be designed or selected (See Article 13) to fit the average ordinate, and the application of the easement or spiral at the ends may then cause sufficient change in the body of the curve to require a different mean ordinate, and a consequent new design or selection of the easement or spiral. It will nearly always be found preferable to dispose of the adjustments necessary for the spiral before those of the body of the curve are attempted. To facilitate this the proposed ordinates for the easements should be written in beside the original ordinates with which they most nearly agree.

Sharp and Flat Places—The next step is to separate the curve into its sharp and flat places. These several groups will consist essentially of ordinates which on the ends are similar, and either less or greater than the average; and which between these, or at the middle, are the direct opposite in value of those on the ends. That is, each sharp spot must have a flat spot either side of it to absorb the effect of the inward throw necessary, and each flat spot must have a sharp spot on either side to receive the outward throw necessary. These sharp

PRELIMINARY STUDY OF THE CURVE

and flat places must have a mean which is in practical agreement with the general mean, and they must be balanced in order to form a series that will be possible of adjustment.

For example, if the sum of the errors of the sharp place is 2 in., the sums of the errors of the two accompanying flat places must be approximately equal and their combined sum equal to 2 in. When this exact balance of positive and negative error does not obtain, adjacent throw must be had to render the series symmetrical. In testing a series to see if the errors balance, it is useful to write the several errors of each end of a selected group with their sums, which should be equal or nearly so; and, separately, the errors of the middle of the group with their sum, which should equal the combined sums of the errors of the ends.

This examination of the curve is necessary to disclose a general deficiency, which may appear at first glance as merely a permissible inaccuracy in detail. Thus, although the $\frac{1}{8}$ has been found to furnish a satisfactory margin of correctness, a succession of ordinates $\frac{1}{8}$ in. in error, accompanied by the requisite group on either side $\frac{1}{8}$ in. in error in the opposite direction, might require a substantial throw for proper adjustment. A careful study of the examples given will throw further light upon this feature of curve solution.

CHAPTER III.

THE SOLUTION OF STRING-LINING PROBLEMS.

7. RULES FOR SOLVING CURVE PROBLEMS

The solution is based on the general proposition that: for an assemblage of ordinates, wherein the first and last ordinates are below the mean and the middle ones above it, the throw is *inward*; and where the first and last ordinates are above the mean and the middle ones below it, the throw is *outward*.

Rule for Determining Throw—While no exact relation exists between error and correction, it will be found that *the throw at the middle of a series is approximately equal to the sum of the errors both above and below the mean of the series; or to twice the sum either of the errors above or of those below the mean.* If the sum of all the errors is employed the working mean may be used; if double the sum of the errors one side or the other, the exact mean must be used. This rule is practically exact when the number of ordinates in a series is odd. When the number of ordinates is even the throw will be slightly more at the point next to the middle in the half that requires the greater correction; and in the other half the throw will be slightly less.

After applying the computed correction to the middle, the solution should progress toward each end in turn, bearing in mind,

first, that the sum of the throws at the two points on either side of the middle must be equal to twice the difference between the resultant at the middle and the adopted mean; and then, that each succeeding throw must be such as to make the resultant nearer the middle equal to this mean; and, finally, that the resultant at the third station from either end of the group must be approximately equal to the end ordinate, so that the final throw at the station between them will correct all three points at once.

Ideal Easement—In the course of the solution due regard must be given to the easements of the curve. The most satisfactory spiral is obtained by diminishing the full ordinate a certain number of units for the ordinate at the end station of the body of the curve, and one unit less for the ordinate at each successive station in turn. The detailed method of determining the value of the unit is described under the article headed "Spiral by Middle Ordinates." The maximum number of units will depend upon the amount of superelevation and its rate of decrease, and should be one less than the number of stations in the run-off. The example given below is from an actual case, (analyzed farther on), and is for a 3 deg. curve and 100 ft. chords. The maximum number of units is seven, and each has a value of $\frac{9}{32}$ in., producing ordinates as follows: 8, 6, $4\frac{1}{4}$, $2\frac{7}{8}$, $1\frac{5}{8}$, $\frac{7}{8}$ and $\frac{1}{4}$ in. An example is also given of a spiral between the two parts of a compound curve, taken from the same case, in which a 3-deg. curve is joined to

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a 1-deg. 50-min. curve, with resulting ordinates of: 8, $6\frac{1}{4}$, $5\frac{3}{8}$ and $4\frac{3}{4}$ in. In this case the maximum number of units is three and the value of the unit $\frac{9}{16}$ in.

Practical Easement—These are examples of the ideal easement, but it should be noted that the spiral curve admits of some modification on its lighter portion. An example is given of the easement in another actual case, which is that of a main line curve carrying a daily traffic of 250 trains at an authorized speed of 50 miles per hour. The deflections are from a 75-ft. string and are as follows:

Degree	5'	10'	15'	20'	25'	30'	35'
Ordinate	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
Superelevation....	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{5}{8}$
45' 1° 1°21'		1°47'	2°17'	2°52'	3°33'	4°19'	4°19'
1½ 1½ 2		2½	3½	4¼	5¼	6¾	6¾
3 3¾ 3¾		4½	4½	4¾	5¼	5¾	6

The degree of curve at the several points on the easement is shown above the ordinates, and the superelevations are shown below them. It will be noted that the full elevation is attained at a point on the body of the curve two stations beyond the end of the easement. The run-off is carried through 16 stations at a uniform rate of 1 in. to 100 ft.

Errors in Designing Easements—The worst possible error, and a not uncommon one, is to make the ordinates in the easement decrease at a uniform rate. This practice is responsible for the deficiencies noticeable at the ends of curves which are otherwise perfectly alined and excellently maintained. The ordi-

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nates in the first of the above cases if designed in this incorrect manner would be as follows: $7\frac{7}{8}$, $6\frac{3}{4}$, $4\frac{1}{2}$, $3\frac{3}{8}$, $2\frac{1}{4}$, $1\frac{1}{8}$ in. A comparison of these figures with the true spiral shows the wide variation of the two. In the last case cited, the ordinates by the false method would be the same as the figures for superelevation. It is readily seen that at the point where an ordinate of $\frac{3}{8}$ in. would occur, indicating a curvature of 0 deg. 15 min., only $\frac{3}{8}$ in. of superelevation would obtain, and this certainly is insufficient for high speed. Farther on the spiral curve is fully described and a method given for its application both by the instrument and the string.

8. EXAMPLES IN CURVE SOLUTION.

The first five examples illustrate the elementary principles in the string-lining of curves, and further examples are given in all of which the various processes of the solution are fully described. A final example is given in which every feature of curve adjustment is illustrated.

In the solutions the throw is distinguished by a circle enclosing it; an arrow indicates the direction of the throw, (to the left for inward throw and to the right for outward throw); and a letter, when used, indicates the order in which the corrections are applied, a hexagon enclosing the station number indicates the full elevation point, and a rectangle the level point.

Examples 1 to 4—These examples are quite simple, and the successive steps will be minutely de-

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scribed in order that every detail of the solution may be fully understood. It is presumed the diagram in Fig. 1 has been studied, and the terms "throw" and "resultant," as used, are entirely clear. An inspection of the group of five ordinates in Examples 1 and 2 discloses that both form a perfect series, in which the ordinates either side the middle are exactly balanced; and a simple calculation shows the mean of the ordinates to be $1\frac{3}{4}$ in. In Example 1, the end ordinates are less and the intermediate ordinate is greater than the mean, and the indicated throw, therefore, inward; while in Example 2 the end ordinates are greater and the intermediate ordinate is less, and the indicated throw, therefore, outward.

In Example 1, the average ordinate for the whole curve is $1\frac{3}{4}$ in.; by comparing the actual ordinates (column 2, example 1) with $1\frac{3}{4}$ in., the errors are, in succession, $\frac{1}{4}$ in., 0, $\frac{1}{2}$ in., 0, $\frac{1}{4}$ in., and their arithmetical sum is 1 in., which is the throw at the middle of the series. This inward throw at Sta. 3 diminishes the ordinate at that station to a resultant $1\frac{1}{4}$ in., and the effect of this inward throw is to increase the ordinates at Sta. 2 and Sta. 4 one-half the amount of the throw, or $\frac{1}{2}$ in., and the resultants at those two points thus become $2\frac{1}{4}$ in.

The sum of the throws at Sta. 2 and Sta. 4 must equal twice the difference between the resultant at Sta. 3 ($1\frac{1}{4}$ in.), and the desired final ordinate ($1\frac{3}{4}$ in.), and will therefore equal 1 in.; and as

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both halves of the series are symmetrical, the throws at Sta. 2 and Sta. 4 will be equal, and will each be $\frac{1}{2}$ in. Applying the inward throw of $\frac{1}{2}$ in. at Sta. 2, the resultant $2\frac{1}{4}$ in. is reduced to the desired mean, and the ordinate at Sta. 1 is increased by one-half of $\frac{1}{2}$ in., or $\frac{1}{4}$ in., bringing it to the desired mean and at the same time the first resultant at Sta. 3 is also increased by $\frac{1}{4}$ in. to a new resultant $1\frac{1}{2}$ in. It will now be noted that this resultant equals the last ordinate in the

EXAMPLE 1			EXAMPLE 2.		
Station	Ordinate	Solution	Station	Ordinate	Solution
1	$1\frac{1}{2}$	$1\frac{3}{4}$	6	2	$1\frac{3}{4}$
2	$1\frac{3}{4}$	$2\frac{1}{4} \leftarrow (\frac{1}{2}) b 1\frac{3}{4}$	7	$1\frac{3}{4}$	$1\frac{1}{2} b (\frac{1}{2}) \rightarrow 1\frac{3}{4}$
3	$2\frac{1}{4}$	$\leftarrow (1) a 1\frac{1}{4} 1\frac{1}{2} 1\frac{3}{4}$	8	$1\frac{1}{4}$	$a (1) \rightarrow 2\frac{1}{4} 2 1\frac{3}{4}$
4	$1\frac{3}{4}$	$2\frac{1}{4} \leftarrow (\frac{1}{2}) c 1\frac{3}{4}$	9	$1\frac{3}{4}$	$1\frac{1}{4} c (\frac{1}{2}) \rightarrow 1\frac{3}{4}$
5	$1\frac{1}{2}$	$1\frac{3}{4}$	10	2	$1\frac{3}{4}$
EXAMPLE 3.			EXAMPLE 4.		
Station	Ordinate	Solution	Station	Ordinate	Solution
11	2	$1\frac{3}{4}$	19	$1\frac{1}{2}$	$1\frac{3}{4}$
12	$1\frac{1}{2}$	$1\frac{1}{4} b (\frac{1}{2}) \rightarrow 1\frac{3}{4}$	20	2	$2\frac{1}{4} \leftarrow (\frac{1}{2}) b 1\frac{3}{4}$
13	$1\frac{1}{2}$	$a (\frac{1}{2}) \rightarrow 2 1\frac{3}{4}$	21	2	$\leftarrow (\frac{1}{2}) a 1\frac{1}{2} 1\frac{3}{4}$
14	$1\frac{3}{4}$	$1\frac{1}{2} 1\frac{3}{4}$	22	$1\frac{3}{4}$	$2 1\frac{3}{4}$
15	$1\frac{3}{4}$	$2\frac{1}{4} \leftarrow (\frac{1}{2}) d 1\frac{3}{4}$	23	$1\frac{3}{4}$	$1\frac{1}{4} d (\frac{1}{2}) \rightarrow 1\frac{3}{4}$
16	$2\frac{1}{4}$	$\leftarrow (1) c 1\frac{1}{4} 1\frac{1}{2} 1\frac{3}{4}$	24	$1\frac{1}{4}$	$c (1) \rightarrow 2\frac{1}{4} 2 1\frac{3}{4}$
17	$1\frac{3}{4}$	$2\frac{1}{4} \leftarrow (\frac{1}{2}) e 1\frac{3}{4}$	25	$1\frac{3}{4}$	$1\frac{1}{4} e (\frac{1}{2}) \rightarrow 1\frac{3}{4}$
18	$1\frac{1}{2}$	$1\frac{3}{4}$	26	2	$1\frac{3}{4}$

Examples 1 to 4, Problems in String Lining.

series, as should be the case, and the final inward throw of $\frac{1}{2}$ in. at Sta. 4 reduces the resultant at Sta. 4 to the desired mean, and at the same time

increases the second resultant at Sta. 3 and the ordinate at Sta. 5 to the desired mean.

The processes in Example 2 are exactly similar except that the outward throws increase the successive ordinates and resultants, and the effect is to decrease the adjacent ordinates or resultants. It will be noted that the errors in Example 2 are also $\frac{1}{4}$ in., 0, $\frac{1}{2}$ in., 0 and $\frac{1}{4}$ in., and the middle throw 1 in., as in Example 1.

Examples 3 and 4 illustrate the case where an adjacent throw is necessary to render the groups Sta. 14 to Sta. 18 and Sta. 22 to Sta. 26 each a practical series. As will be seen readily it only needs that the ordinate at Sta. 14 be reduced to $1\frac{1}{2}$ in., and that at Sta. 22 increased to 2 in. to render both an evenly balanced series.

The half function of an outward throw of $\frac{1}{2}$ in. at Sta. 13, and of an inward throw of $\frac{1}{2}$ in. at Sta. 21, reduces the ordinate at Sta. 14 and increases the ordinate at Sta. 22 to the required resultants; and incidentally renders the resultants at Sta. 13 and Sta. 21 equal respectively to the ordinates at Sta. 11 and Sta. 19, so that a final outward throw of $\frac{1}{2}$ in. at Sta. 12 and inward throw of $\frac{1}{2}$ in. at Sta. 20 renders the first three resultants in each example equal to the desired mean.

After this process the remaining members in the two examples become identical with Examples 1 and 2 and their final solution is exactly similar.

If these four examples are now considered as combined into one problem it will be seen how im-

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portant is the question of determining by the preliminary study of the curve the treatment to be accorded. The faculty of being able to do this quickly is rapidly acquired by practice.

Example 5—Example 5 has been selected because it illustrates the making of a spiral for the ends and because it contains a typical sharp and flat place.

EXAMPLE 5. (0°45' Curve with 100' String.)								
Sta.	Ord.	Solution	Sta.	Ord.	Solution	Sta.	Ord.	Solution
1	0	$\frac{1}{8}$	12	$2\frac{3}{8}$	$(1\frac{1}{2}) \rightarrow 1\frac{1}{8} \rightarrow 1\frac{1}{2} \rightarrow 2$	23	$1\frac{7}{8}$	$1\frac{1}{4} \rightarrow (\frac{7}{8}) \rightarrow 2\frac{1}{8} \rightarrow 2$
2	$\frac{3}{8}$	$(\frac{3}{8}) \rightarrow 0 \rightarrow \frac{1}{4}$	13	2	$2\frac{5}{8} \rightarrow (1) \rightarrow 1\frac{5}{8} \rightarrow 2$	24	$2\frac{1}{8}$	$1\frac{5}{8} \rightarrow (\frac{3}{8}) \rightarrow 2$
3	$\frac{7}{8}$	$1\frac{1}{8} \rightarrow (\frac{5}{8}) \rightarrow \frac{1}{2}$	14	2	$2\frac{1}{2} \rightarrow (\frac{5}{8}) \rightarrow 1\frac{7}{8} \rightarrow 2$	25	$2\frac{1}{4}$	2
4	$\frac{7}{8}$	$1\frac{1}{4} \rightarrow \frac{7}{8}$	15	$1\frac{7}{8}$	$2\frac{1}{4} \rightarrow (\frac{1}{4}) \rightarrow 2$	26	$1\frac{3}{4}$	2
5	$1\frac{1}{8}$	$(\frac{5}{8}) \rightarrow 1\frac{1}{4} \rightarrow 1\frac{3}{8}$	16	$1\frac{7}{8}$	2	27	$2\frac{3}{8}$	$(\frac{5}{8}) \rightarrow 1\frac{3}{4} \rightarrow 2$
6	$1\frac{5}{8}$	$1\frac{3}{8} \rightarrow (\frac{5}{8}) \rightarrow 2$	17	$2\frac{1}{4}$	2	28	$1\frac{3}{4}$	$2 \rightarrow (\frac{5}{8}) \rightarrow 1\frac{3}{8}$
7	$2\frac{1}{4}$	2	18	$2\frac{1}{8}$	$1\frac{5}{8} \rightarrow (\frac{3}{8}) \rightarrow 2$	29	$\frac{7}{8}$	$1\frac{1}{4} \rightarrow \frac{7}{8}$
8	$1\frac{3}{4}$	2	19	2	$1\frac{3}{8} \rightarrow (\frac{7}{8}) \rightarrow 2\frac{1}{4} \rightarrow 2$	30	$\frac{1}{8}$	$(\frac{5}{8}) \rightarrow \frac{3}{4} \rightarrow \frac{1}{2}$
9	$2\frac{1}{8}$	$2\frac{3}{8} \rightarrow (\frac{3}{8}) \rightarrow 2$	20	$1\frac{7}{8}$	$1\frac{1}{8} \rightarrow (1\frac{1}{4}) \rightarrow 2\frac{3}{8} \rightarrow 2$	31	$\frac{1}{8}$	$-\frac{1}{8} \rightarrow (\frac{3}{8}) \rightarrow \frac{1}{4}$
10	$1\frac{7}{8}$	$2\frac{1}{4} \rightarrow (\frac{3}{8}) \rightarrow 1\frac{7}{8} \rightarrow 2$	21	$1\frac{3}{4}$	$(1\frac{1}{2}) \rightarrow 3\frac{1}{4} \rightarrow 2\frac{5}{8} \rightarrow 2$	32	$\frac{1}{4}$	$\frac{1}{8}$
11	$2\frac{1}{8}$	$2\frac{3}{4} \rightarrow (\frac{1}{8}) \rightarrow 1\frac{7}{8} \rightarrow 2$	22	$1\frac{7}{8}$	$1\frac{1}{8} \rightarrow (1\frac{1}{4}) \rightarrow 2\frac{3}{8} \rightarrow 2$			

Example 5. Problems in String Lining.

The spiral for a curve whose ordinate is 2 in. may decrease by 5, 4, 3, 2 and 1 units, respectively, of value $\frac{1}{8}$ in. each, with final figures as obtained, viz.: 2, $1\frac{3}{8}$, $\frac{7}{8}$, $\frac{1}{2}$, $\frac{1}{4}$ and $\frac{1}{8}$ in.

The sharp place between Sta. 8 and Sta. 16 has a total of positive errors of $\frac{5}{8}$ in., and the middle throw at Sta. 12 is twice this, or $1\frac{1}{4}$ in. The sum of the two throws at Sta. 11 and Sta. 13 must be $1\frac{7}{8}$ in. to make the final resultant at Sta. 12, 2 in.; and the throw at Sta. 10 must be $\frac{3}{8}$ in. to make the

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final resultant at Sta. 11, 2 in., and also to make the resultant at Sta. 10 nearly equal to the ordinate at Sta. 8. The throw must be $\frac{5}{8}$ in. at Sta. 14 to make the final resultant at Sta. 13, 2 in. and to make the resultant at Sta. 14 equal to the ordinate at Sta. 16. A final throw of $\frac{3}{8}$ in. at Sta. 9 and $\frac{1}{4}$ in. at Sta. 15 completes the correction of the series.

The flat place between Sta. 17 and Sta. 25 has a total of positive errors of $\frac{3}{4}$ in. and the middle

Sta.	Ord.	Solution				Sta.	Ord.	Solution			
1	$\frac{1}{8}$					13	$\frac{3}{4}$	$\textcircled{2\frac{3}{4}}$	$\frac{3}{2}$	$2\frac{1}{8}$	$\frac{3}{4}$
2	$\frac{1}{4}$	$\textcircled{\frac{1}{8}}$	$\frac{3}{8}$			14	$\frac{1}{2}$	$-\frac{7}{8}$	$\textcircled{2\frac{5}{8}}$	$\frac{1}{4}$	$\frac{3}{4}$
3	$\frac{3}{4}$	$\frac{7}{8}$				15	$\frac{3}{4}$	$-\frac{1}{2}$	$\textcircled{\frac{7}{8}}$	$\frac{1}{8}$	$\frac{3}{4}$
$\textcircled{4}$	$\frac{5}{8}$	$\frac{1}{8}$	$\textcircled{\frac{1}{4}}$	$\frac{7}{8}$		16	$\frac{1}{2}$	$-\frac{3}{8}$	$\textcircled{\frac{1}{8}}$	1	$\frac{3}{4}$
5	1	$\frac{1}{4}$	$\textcircled{1}$	$\frac{3}{4}$	$\frac{7}{8}$	17	1	$\frac{3}{8}$	$\textcircled{\frac{3}{8}}$	$\frac{3}{4}$	
6	$\frac{1}{4}$	$\frac{1}{4}$	$-\frac{1}{4}$	$\frac{1}{4}$	$\frac{7}{8}$	18	1	$\frac{7}{8}$	$\frac{3}{4}$		
7	$\frac{1}{8}$	$\frac{1}{8}$	$\textcircled{\frac{1}{4}}$	$\frac{5}{8}$	$\frac{7}{8}$	19	1	$\frac{5}{8}$	$\textcircled{\frac{1}{4}}$	$\frac{7}{8}$	
8	$\frac{1}{4}$	$\frac{7}{8}$	$\textcircled{\frac{1}{2}}$	$\frac{3}{8}$	$\frac{7}{8}$	20	$\frac{7}{8}$	$\frac{3}{8}$	$\textcircled{\frac{5}{8}}$	1	
9	1	$\frac{1}{4}$	0	$\textcircled{\frac{7}{8}}$	$\frac{7}{8}$	21	$\frac{1}{2}$	$-\frac{1}{8}$	$\textcircled{\frac{1}{8}}$	1	
10	$\frac{3}{8}$	-1	$\textcircled{2\frac{3}{8}}$	$\frac{1}{8}$	$\frac{7}{8}$	22	$\frac{5}{8}$	$\textcircled{1\frac{3}{8}}$	2	$\frac{1}{2}$	
11	$\frac{5}{8}$	$-\frac{3}{4}$	$\textcircled{2\frac{5}{8}}$	$\frac{7}{8}$	$\frac{3}{4}$	23	$\frac{5}{8}$	0	$\textcircled{\frac{1}{4}}$	$\frac{1}{4}$	
12	$\frac{1}{2}$	$-\frac{7}{8}$	$\textcircled{2\frac{7}{8}}$	2	$\frac{3}{4}$	24	$\frac{7}{8}$	$\frac{1}{4}$	$\textcircled{\frac{5}{8}}$	$\frac{7}{8}$	

Example 6. 0 Deg. 20 Min. Curve with

throw at Sta. 21 is twice this, or $1\frac{1}{2}$ in. The sum of the two throws at Sta. 20 and Sta. 22 must be $2\frac{1}{2}$ in. to make the final resultant at Sta. 21 equal 2 in.; and the throws at Sta. 19 and Sta. 23

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must each be $\frac{7}{8}$ in. to make the final resultants at Sta. 20 and Sta. 22 equal 2 in., and to make the resultants at Sta. 19 and Sta. 23 equal or nearly equal to the ordinates at Sta. 17 and Sta. 25. A final throw of $\frac{3}{8}$ in. at Sta. 18 and Sta. 24 completes the correction of the series.

The adjustment of the spirals involves only detailed correction, and does not follow any set rule.

It is apparent there is a sharp place at Sta. 2 and Sta. 3 and at Sta. 27 and 28, and that there is similarly a flat place at Sta. 5 and Sta. 6 and at Sta. 30 and Sta. 31.

Sta.	Ord.	Solution			
25	$\frac{1}{4}$	$\frac{7}{8}$			
26	$\frac{3}{4}$				
27	$\frac{7}{8}$				
28	$\frac{3}{4}$	$\frac{7}{8}$			
29	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{7}{8}$	
30	$\frac{7}{8}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$
31	$\frac{1}{8}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{7}{8}$
32	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{4}$	
33	$\frac{5}{8}$	$\frac{7}{8}$			
34	$\frac{3}{8}$				
35	$\frac{1}{8}$				

t. String.

Example 6—Example 6 has been selected for solution as requiring the use of all the above rules. A study of this curve shows: that the easement Sta. 1 to Sta. 3 is not quite a true spiral; that there is a sharp place between Sta. 5 and Sta. 9; that both an outward throw on one side and an inward throw on the other will be necessary to elim-

inate this sharp place; that there is a flat place between Sta. 8 and Sta. 17; that there is a flat place between Sta. 18 and Sta. 25; that there is a sharp place between Sta. 28 and Sta. 33; and that the cor-

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rection of the latter must also restore the spiral feature between Sta. 33 and 35.

The average for the body of the curve is $1\frac{3}{8}$ in., but in line with the adopted standard it will be proper to work to either $\frac{3}{4}$ in. or $\frac{7}{8}$ in. Evidently since Sta. 3 and Sta. 4 are less than the mean, while Sta. 5, Sta. 6 and Sta. 7 are greater, two other stations below the mean are needed to complete the series. But Sta. 8 and Sta. 9 will also be a part of a series requiring outward throw. We must estimate for the time being the value of the resultants at Sta. 8 and Sta. 9 after the prospective outward throws at Sta. 9 and Sta. 10, which resultants we assume may become equal severally to the ordinates at Sta. 3 and Sta. 4. The average of this series is then $\frac{7}{8}$ in. and, applying the rule, the sum of the positive errors being $\frac{3}{4}$ in., the correction at Sta. 6 is $1\frac{1}{2}$ in.

It is apparent that the sum of the throws at Sta. 5 and Sta. 7 must be $2\frac{1}{4}$ in., and that the use of 1 in., at Sta. 5 and $1\frac{1}{4}$ in. at Sta. 7 will render the resultant at these two points equal to the ordinate at Sta. 3 and the resultant at Sta. 9, respectively; and that the completed solution will attain the desired average.

Noting that the resultants at Sta. 8 and 9, *after the inward throw of $\frac{1}{2}$ in. at Sta. 8*, are $1\frac{3}{8}$ in. and $1\frac{1}{4}$ in., we find that the mean of the series Sta. 8 to Sta. 18 is $\frac{3}{4}$ in., and that the sum of the positive errors is $1\frac{3}{8}$ in.; the throw should be twice this or $2\frac{3}{4}$ in. at Sta. 13. The resultant at Sta.

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13 is $3\frac{1}{2}$ in., and the sum of the throws at Sta. 12 and Sta. 14 must be equal to $5\frac{1}{2}$ in. in order to make the final resultant $\frac{3}{4}$ in. at Sta. 13.

As greater throw is evidently necessary for the first half we try $2\frac{7}{8}$ in. at Sta. 12 and $2\frac{5}{8}$ at Sta. 14. It is now easy to follow to the end; the next throw must be $2\frac{5}{8}$ in. to reduce the resultant at Sta. 12 to $\frac{3}{4}$ in., and the next $2\frac{3}{8}$ in. to reduce the resultant at Sta. 11 to $\frac{3}{4}$ in. The resultant at Sta. 10 now approximates the resultant at Sta. 8, and a final throw of $\frac{7}{8}$ in. at Sta. 9 renders the resultant at this station and also at Sta. 8 and Sta. 10, $\frac{7}{8}$ in., and confirms the correctness of the resultants assumed for Sta. 8 and Sta. 9 in the beginning of the solution. We follow a similar method between Sta. 14 and Sta. 18, when, the resultant for Sta. 16 approximating the ordinate at Sta. 18, the last throw of $\frac{3}{8}$ in. completes the correction.

The correction of the series from Sta. 18 to Sta. 25, the average ordinate of which is $\frac{7}{8}$ in. and sum of positive errors $\frac{11}{16}$ in., with maximum correction therefore $1\frac{3}{8}$ in., follows the general lines already described.

The elimination of the sharp place, Sta. 28 to Sta. 33 presents the case of a series with an even number of members. The computed maximum throw is $\frac{3}{4}$ in., but as the higher stations require greater correction, $\frac{7}{8}$ in. is adopted for Sta. 31, and $\frac{5}{8}$ in. for Sta. 30.

The resultant at Sta. 33 completes a practical

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Sta.	Ord.	Solution			Sta.	Ord.	Solution			Sta.	Ord.	Solution		
1	0	4	5	6	17	7	8	9	10	33	7	6	7	8
2	3	5	6	7	18	7	8	9	10	34	7	6	7	8
3	4	6	7	8	19	6	7	8	9	35	6	7	8	9
4	5	7	8	9	20	4	5	6	7	36	5	6	7	8
5	15	8	9	10	21	4	5	6	7	37	5	6	7	8
6	3	9	10	11	22	2	3	4	5	38	8	7	8	9
7	5	10	11	12	23	0	1	2	3	39	8	7	8	9
8	7	11	12	13	24	1	1	2	3	40	7	8	9	10
9	7	12	13	14	25	1	2	3	4	41	8	7	8	9
10	7	13	14	15	26	4	5	6	7	42	7	8	9	10
11	7	14	15	16	27	8	9	10	11	43	6	7	8	9
12	6	15	16	17	28	8	9	10	11	44	3	4	5	6
13	7	16	17	18	29	8	9	10	11	45	2	3	4	5
14	6	17	18	19	30	7	8	9	10	46	1	2	3	4
15	6	18	19	20	31	7	8	9	10	47	3	4	5	6
16	7	19	20	21	32	8	9	10	11	48	0	1	2	3

Example 7. Spirals for Reversed Curve.

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spiral, and a slight detail throw at Sta. 2 accomplishes the same result.

Example 7—The problem of the reversed curve in Example 7 is given because it illustrates the utility of the string method in providing practical easements in an extreme case. The location map gives the following data for the curves: 1493+74.8, P. C. 7°R., 1498+42.8, P. T., 1499+78.5, P. C. 8°L., 1506+50, P. T. It will be observed that a tangent length of but 135.7 ft. was provided between the curves upon which to run off a superelevation of 5 in. for the one curve and 5½ in. for the other, these being proper for the speed prescribed by the time-table, namely, 40 miles per hour.

An effort had previously been made to adjust the curves, with fair results as regards the body of the curves, but without success for the easements between them. The run-off of the lighter curve had been commenced at Sta. 16 and ended at Sta. 22 and the approach of the other curve started at this point and completed at Sta. 33. The effect of this was to establish at Sta. 18 and Sta. 28, where, as the curves were then alined, the full elevation should have occurred, elevations respectively of 3½ in. and 3¼ in., which virtually limited the speed used to 30 miles per hour.

The general problems of the two curves are quite similar and, as always occurs when easements not provided for are added, necessitated the sharpening of the curves throughout, which in both cases amounted to ¼ of one degree, or 3 per cent of the

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final degree. The further problem in each was to utilize a sharp spot for throwing the curves outward as much as possible, thus introducing a flat-spot near the end of the main curve which was needed to receive a heavy inward throw on the ends, the effect of which would be to move the ends of the main curve one station farther from the reversing point. The advantage to be thus gained consisted in providing additional length of easement needed to modify the rate of the run-off, which was finally established as 1 in. to 36 ft. for both curves.

The detailed corrections preceding Sta. 13 and following Sta. 38 are general and need no explanation. The necessary sharp place on the first curve occurs at Sta. 13 and the outward throws leave the resultant at Sta. 16 equal to $6\frac{5}{8}$ in., which with the flat place at Sta. 23 permits of the inward throw between these points. The easement between Sta. 19 and Sta. 23 is readily designed with a maximum of 6 units and a value of $1\frac{1}{2}$ in. for the unit, and supplies ordinates as follows: $5\frac{1}{8}$, $3\frac{1}{2}$, $2\frac{1}{8}$, 1, $\frac{3}{8}$ in., the sum of which is $12\frac{1}{8}$ in. The sum of the resultant at Sta. 16 and the seven original ordinates following is 35 in. The test of whether the projected easement is possible will lie in this sum being approximately equal to the sum of the ordinates in the easement and the normal ordinates for the remaining three stations, which is found to be the case.

The ideal ordinates of the easement should be placed opposite their respective stations, when the

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successive errors between Sta. 16 and Sta. 23 are $-\frac{5}{8}, -\frac{1}{8}, -\frac{1}{4}, +1\frac{3}{8}, +1, +\frac{1}{2}, -\frac{1}{2}, -\frac{3}{8}$ in., the arithmetical sum of which is $4\frac{3}{4}$ in. As the number of stations in the series is even, this will be the correction at the exact middle of the series and the use of $4\frac{7}{8}$ in. at Sta. 19 and $4\frac{5}{8}$ in. at Sta. 20 is seen to furnish satisfactory adjustment.

The required sharp place in the second curve is found between Sta. 36 and Sta. 38. As the outward throw found possible is considerable it will be instructive to trace the correction through the series. Sta. 30, already flat, will plainly be the end of the series of outward throw and the point to receive the prospective inward throw preceding it. Since Sta. 36 and Sta. 38 together have positive error of $\frac{5}{8}$ in., it will be necessary for the inward throw at Sta. 29 to be large enough to render the resultant from this source at Sta. 30 equal to $8\frac{3}{4}$ in., or there would otherwise not be a practical series for the outward throw. The errors between Sta. 30 and Sta. 36 are then: $+\frac{1}{2}, -\frac{3}{8}, -\frac{3}{8}, -\frac{3}{8}, +\frac{1}{4}, +\frac{1}{4}$ in., the arithmetical sum of which is $2\frac{1}{8}$ in., which is the throw at Sta. 34. The resultant, 10 in., at this station exceeds the desired final ordinate by $1\frac{3}{4}$ in., which last figure therefore represents the approximate throw at the adjacent points. The resultants at Sta. 33 and Sta. 35 exceed the mean ordinate by $\frac{1}{2}$ in. and $\frac{3}{8}$ in. respectively and the throws at Sta. 32 and Sta. 36 are twice these or $1\frac{1}{8}$ in. and $\frac{7}{8}$ in. Final throws of $\frac{5}{8}$ in. at Sta. 31 and $\frac{3}{8}$ in. at Sta. 37 complete the correction of the series, except that the resultant

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at Sta. 30 is reduced to $7\frac{1}{2}$ in. The flat places at Sta. 30 and at Sta. 23, Sta. 24 and Sta. 25 furnish the desired opportunity to make the inward throw.

The easement for this case follows the same general lines as for the preceding case except that the ordinate being greater and the maximum number of units the same, the value of the unit will be larger and it is found to be $25/64$ in. The ordinates of the proposed easement are. $\frac{3}{8}$, $1\frac{1}{8}$, $2\frac{3}{8}$, $3\frac{7}{8}$, $5\frac{7}{8}$ in. The sum of the ordinates between Sta. 23 and Sta. 29 and the resultant at Sta. 30 is $38\frac{3}{8}$ in., while the sum of the three uniform ordinates and the ordinates of the projected easement is also $38\frac{3}{8}$ in., and the easement is therefore practicable.

Placing the proposed ordinates for the easement opposite the respective stations, the errors between Sta. 23 and Sta. 30 are in their order $-\frac{3}{8}$, $-\frac{1}{8}$, $-\frac{7}{8}$, $+\frac{1}{4}$, $+2\frac{1}{4}$, $-\frac{1}{8}$, $-\frac{1}{4}$, $-\frac{3}{4}$ in., and their arithmetical sum is 5 in. But the number of stations again being even this will be the correction for the exact middle of the series and the corrections at Sta. 26 and Sta. 27 will lie above and below this figure. The use of $3\frac{7}{8}$ in. at Sta. 26 and $5\frac{7}{8}$ in. at Sta. 27 and proper succeeding corrections, effects the desired result.

At first thought it might seem that the presence of a $\frac{3}{8}$ in. ordinate at Sta. 23 for both easements makes the two curves encroach upon each other; but in fact the curve of each ends at this station and the ordinate attaches to the curvature beyond in each case.

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Referring back to the original notes of the alinement, it is seen that the several adjustments, together with the utilization of the plain principles of mechanics, which permits the full elevation to be established two stations from the end of the main curve, have resulted in an extension of the available distance for running off the combined superelevations from 136 ft. to 372 ft. This makes possible the use of 5 in. and $5\frac{1}{2}$ in. superelevation, respectively, which can be run off at a safe rate of 1 in. to 36 ft. A speed of 40 miles per hour is then both safe and comfortable, whereas the original alinement, with full elevation at the P. C. and the run-off made at nearly the same rate, would have permitted a combined superelevation of but 5 in., and the curves would have been only fit for operation at 30 miles per hour.

Example 8—The solution of the reversed curve in Example 8 illustrates the utility of the string method in effecting a considerable change whereby a very unfavorable alinement at the point of reverse was corrected and an increase in the superelevation made possible. These adjustments operated to withdraw a speed restriction of 15 miles per hour which had always existed and which required constant maintenance of slow signals. The improvement was especially important because the point was at one end of the ruling grade of the branch road.

A careful study of the original ordinates will show that, although some detailed correction was

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Sta.	Ord.	Solution				Sta.	Ord.	Solution				Sta.	Ord.	Solution			
0						11	9½	←(25) 6	8	8½	8½	22	4½	1 →(9) 10½	10½	4½	
1	½					12	9	←(26) 10½	8½	8½	8½	23	4½	-2½ →(13) 10½	10½	4½	
2	7/16					13	6⅞	7½	8	8	8	24	4½	-3 →(13½) 10½	10½	4½	
3	1¼		1½	←(7) 8½		14	6½	7¼	8½	8	8	25	4½	-17/8 →(12) 10½	10½	4½	
4	4¼		4⅜	←(15) 4⅜	2¼	15	6¼	7	5⅝	5¼	5¼	26	4½	-2⅝ →(11½) 9	9	4½	
5	8		8⅞	←(23) 8⅞	6½	16	4	←(18) 25/8	3¼	3¼	3¼	27	4½	-25/8 →(9½) 7	7	4½	
6	7		8½	←(7) 8½	9	17	1	15/8				28	2¼	-2½ →(5½) 3½	3½	2¼	
7	6⅝		5⅝	←(15) 5⅝	7½	18	5/8	0	5/8			29	2½	-5/8 →(17) 1½	1½	1	
8	10		9½	←(7) 9½	7¾	19	5	3¼	2½	4¼	4¼	30	5/8	-1/4 →(5) 3/8	3/8		
9	8¼		8⅞	←(7) 8⅞	8	20	3⅞	←(35) 1⅞	7½	3⅝	3⅝	31	0	0	0		
10	6⅞		7½	←(8) 8½	8½	21	3¼	1⅞	9½	4¼	4¼	32					

Example 8. 8 Deg. and 4 Deg. Reversed Curve with 62 Ft. String.

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required upon the body of the curve, the principal defect was the lack of sufficient easement between the curves to properly run off the combined superelevation that the general branch speed of 40 miles per hour required. The original alinement indicates the degree of the one curve as 8 deg. and of the other as 4 deg., with a tangent distance of but 105 ft. between them. Previous adjustments had resulted in an extension of the available run-off distance to a total of 6 stations, which allowed a combined superelevation of 5 in. for the two curves. Considering the maximum curvature of 10 deg. on the one and of 5 deg. on the other, this would suffice for a speed of 28 miles per hour. In order, however, to provide for a speed of 40 miles per hour, requiring combined superelevation of $7\frac{1}{2}$ in. for the two curves, it was necessary to extend the run-off distance two more stations.

It is plain that this cannot all be done by any scheme of detailed correction at the immediate point of reverse, but an extension of one station was thus effected. The only way remaining is to sharpen the curves, which would of course shorten the tangent distance of each; but the 8 deg. curvature is already the maximum for 40-mile speed. It is thus only possible to make this adjustment through the lighter curve, and it is seen that a maximum throw of $13\frac{1}{4}$ in. not only eliminates the sharp spot at Sta. 19, but extends the available run-off one station farther and completes the attainment of the result that was sought.

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EXAMPLE 9									
Sta.	Ord.	Solution						Throws	
7	$\frac{5}{8}$	Preliminary Adjustment				$\frac{7}{8}$			
8	$\frac{7}{8}$					$\frac{1}{4}$	$\leftarrow \frac{3}{8}$		$\leftarrow \frac{3}{8}$
9	$\frac{7}{8}$					$\frac{1}{4}$	$\leftarrow \frac{5}{8}$	$\frac{7}{8}$	$\leftarrow \frac{5}{8}$
10	1					$\frac{1}{2}$	$\leftarrow \frac{7}{8}$	$\frac{5}{8}$	$\leftarrow \frac{7}{8}$
11	$\frac{1}{4}$	$\frac{3}{4}$				$\frac{5}{8}$	$\leftarrow \frac{1}{8}$	$\frac{1}{2}$	$\leftarrow \frac{1}{8}$
12	1	$\frac{1}{8}$	$\leftarrow \frac{1}{8}$	$\frac{1}{8}$		$\frac{1}{8}$	$\leftarrow \frac{1}{8}$	$\frac{3}{8}$	$\leftarrow \frac{1}{8}$
13	$\frac{1}{2}$	$\leftarrow \frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\leftarrow \frac{1}{4}$	-1	$\frac{1}{2}$	$\leftarrow \frac{1}{2}$
14	1	$\frac{1}{8}$	$\leftarrow \frac{1}{8}$	$\frac{1}{8}$		$\frac{1}{8}$	$\leftarrow \frac{1}{8}$	$\frac{3}{8}$	$\leftarrow \frac{1}{8}$
15	$\frac{1}{4}$	$\frac{3}{4}$				$\frac{5}{8}$	$\leftarrow \frac{1}{8}$	$\frac{1}{2}$	$\leftarrow \frac{1}{8}$
16	$\frac{3}{4}$					$\frac{1}{8}$	$\leftarrow \frac{7}{8}$	$\frac{1}{2}$	$\leftarrow \frac{7}{8}$
17	1					$\frac{1}{2}$	$\leftarrow \frac{5}{8}$	$\frac{7}{8}$	$\leftarrow \frac{5}{8}$
18	$\frac{1}{2}$					$\frac{7}{8}$		$\frac{7}{8}$	

EXAMPLE 10									
	Sta.	Ord.	Solution				Errors		
Proposed Spirals	23	$\frac{6}{8}$					+2		
	24	$\frac{3}{8}$	$\frac{6}{8}$				+3		
	25	$\frac{5}{8}$	$\frac{5}{8}$	$\leftarrow \frac{1}{2}$	$\frac{6}{8}$		+3 + 8		
	26	$\frac{4}{2}$	$\frac{4}{2}$	$\leftarrow \frac{7}{8}$	$\frac{3}{8}$	$\frac{6}{8}$		$\frac{-8}{-8} \rightarrow \text{Sum } \frac{3}{8} = \frac{7}{8}$	
	$\frac{27}{8}$	$\frac{5}{8}$	$\leftarrow \frac{3}{8}$	9	$\frac{7}{8}$	$\frac{6}{8}$			
	28	$\frac{5}{8}$	$\frac{3}{4}$	$\leftarrow \frac{5}{8}$	$\frac{7}{8}$	$\frac{6}{8}$			
	$\frac{3}{2}$	29	$\frac{3}{4}$	$\leftarrow \frac{1}{8}$	$\frac{2}{4}$	$\frac{3}{2}$	+3	} After Throw at Station 30	
	$\frac{7}{8}$	30	$\frac{3}{4}$	$\leftarrow \frac{1}{8}$	$\frac{1}{4}$		+4 + 7		
	$\frac{1}{2}$	31	0	$\frac{5}{8}$			-4		
	$\frac{1}{8}$	32	$\frac{1}{2}$	$\leftarrow \frac{1}{8}$	$\frac{3}{8}$		$\frac{+1}{+6} \rightarrow \text{Sum } \frac{15}{8} = \frac{7}{8}$		
	$\frac{5}{8}$	33	$\frac{3}{8}$	$\leftarrow \frac{7}{8}$	$\frac{2}{8}$	$\frac{2}{2}$	-2		
	$\frac{4}{8}$	34	$\frac{4}{8}$	5	$\leftarrow \frac{5}{8}$	$\frac{4}{8}$	-2		
	$\frac{3}{8}$	35	$\frac{4}{8}$	$\frac{4}{8}$					
		36	$\frac{4}{8}$						

Examples 9 and 10. Preliminary Adjustment; Error and Correction.

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Example 9—The problem of Example 9 is somewhat odd but by no means rare in curve adjustment, especially where a roughing-in of the line has not been arranged for, before the test ordinates were taken. It is plain that the presence of the flat spot at Sta. 13 seriously interferes with the general adjustment of the curve, but that when the detailed adjustment is made the general correction is quite apparent. It will be noted that in the preliminary correction the aim was to first draw the curve into an elliptical form, as that is the basic requirement in this system of curve adjustment. The need for this preliminary correction occurs more commonly in light curves than in sharp ones. It is necessary that care be exercised to add the partial throws together when they are in the same direction, or to subtract them when in an opposite direction, to obtain the final resultant correction.

Example 10—The problem of this reversed curve is instructive as showing the development of an easement of the minimum practical length, permitting a run-off at the safe rate of 1 in. to 36 ft., notwithstanding the exceedingly short extent of tangent provided in the original alinement, which was but 65 ft. between a 6 deg. and a 4 deg. curve. It will be seen that 124 ft. of easement and 248 ft. of run-off is available, which is sufficient to take care of the combined superelevation of 7 in. required by the curves. Before the adjustment, no more than $6\frac{1}{4}$ in. of combined superelevation was practicable, and this was only enough for 35 miles per

hour; besides, the difference in ordinates at one station of $3\frac{3}{4}$ in. gave the same effect as a 7 deg. 30 min. curve without easement, and such a condition is improper.

9. APPLICATION OF THE CORRECTIONS.

When the various corrections have been figured it only remains to make the several throws. Any further use of the string is generally unnecessary. The figures for the throws, if worked out by the supervisor, may even be telephoned the foreman with confidence that the result will be a correct alinement.

Use of Pole—For recording the original position of the track and for measuring the extent of the throws, a method by the use of a pole is the most generally satisfactory one. The pole should be of white pine planed on the four sides and should be about 11 ft. long. It is placed against the web of the rail of an adjoining track and at right angles with the rail, and the position of the gage line is then marked upon it. This is done for each of the several points that are to be shifted. The number assigned to the respective station is written over these marks for identification during the course of the lining. In order to avoid interference of the several marks and throws, it is desirable to use both ends of the pole, eight distinct markings being thus possible. But since tracks are seldom exactly parallel, many more indications may be made without confusion, and the record of an entire curve may

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often be carried upon the pole at one time. It will sometimes be found to render the method still more convenient to add to the pole record, marks indicating the proposed as well as the present position of the track.

Upon frequent trials with the pole the progress of the lining will be noted, and the ultimate attainment of the completed throw thus observed. The pole record may be preserved for a day or two to test the corrected line for slight defects that are likely to occur while the track is becoming bedded in its new position; but when the throw is small this will not be necessary.

Line Stakes—Sometimes stakes are set just inside the line of the high rail, being so placed that upon completion of the realining the track will be everywhere a uniform distance from the stakes. This distance should not be less than 6 in. nor more than 12 in. In the event of the solution being made by the supervisor, he can give the foreman, in place of figures for the throw at the various points, the distances to set his stakes from the rail, adding 12 in. to the throws when they are inward, or subtracting the throws from 12 in. when they are outward.

The general use of stakes involves considerable unnecessary labor, and has no advantage in any respect over the pole method, except that on single track stakes are indispensable. It is always permissible to use stakes if there is any question of the correctness of the test ordinates, in order that

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the proposed alinement may be proven with the string before the lining is authorized. In special cases, such as spike lining through switch connections or crossings, it is convenient to mark the original position of the rail directly upon a tie from which the spikes have been withdrawn. In such lining the rule that quarter ordinates are three-fourths the middle ordinate can be employed with advantage.

CHAPTER IV.

SUPERELEVATION OF CURVES.

The matter of superelevation of curves is of equal importance with the adjustment of the alinement. The impracticability of employing a fixed formula for superelevation has been demonstrated. It is now recognized that the rule for equilibrium gives too low an elevation for the lighter curves, and too high an elevation for the sharper curves. It is plainly desirable that the flanges of the wheels shall be constantly in contact with the outer rail of the track. If the motion on the curve were just balanced, each slight irregularity in the line and gage, or unevenness of the superelevation, would cause the flanges to strike the inner and outer rail alternately. This would introduce a decided discomfort in riding. It is well known that the best results are attained upon curves a little above 45 min., provided the line is good and the amount of elevation just sufficient. This cannot be realized upon the lighter curves, and it is for this reason mainly that extremely light curves are unsatisfactory.

The practical superelevation is developed for both the easement and the body of the curve. As the adjustment of the former by means of the spiral is principally for the object of properly running off the superelevation, the spiral is explained in the

next succeeding chapter. The method by ordinates is relatively simple, but some practice is necessary to be able at once to fit a working spiral to the ordinates found, with the least possible throwing. The method by the instrument will not be of direct concern to the trackman, but the ease of its application will leave the engineer no excuse for omitting it in future locations.

The analysis of lining and elevation corrections is of interest as showing the direct relation each bears to the other. Remembering that light curves require the greater comparative elevation, and appreciating that the run-off must be made at some regular rate, there is no alternative but to adopt for the easements a curve that begins with flat curvature and increases in a definite progression to the full degree of curve.

10. APPROACH AND RUN-OFF OF CURVES.

After the curve has been realigned and defective easements corrected, it may be necessary to re-surface the run-off; as the point of full elevation, both from theoretical considerations and as a matter of experience, should generally be established close to the station that is next to the last point of full ordinate toward the middle of the curve, provided the stations are not less than 30 ft. nor more than 50 ft. apart. This is for the reason that the force tending to throw the car outward, which is called the centrifugal force, does not reach its greatest effect until the car is wholly upon the

curve. It should be understood that the body of the curve extends to the first station back of the last point of full ordinate toward the ends of the curve.

High-Speed Track—The approach and run-off of curves in high-speed track should be placed in proper relation with the curve of the easement, and be so designed that the rate of increase or decrease of elevation may be uniform and not greater than $\frac{1}{2}$ in. to 33 ft. The preferable rate is $\frac{1}{3}$ in. to 33 ft., but for light curves $\frac{1}{4}$ in. to 33 ft. is quite satisfactory.

Moderate Speed Track—The approach and run-off in tracks operated at moderate speed, or in sidings operated at low speed, may be made at a somewhat greater rate than $\frac{1}{2}$ in. to 33 ft., but the rate should never exceed 1 in. to 33 ft. Tests with modern equipment have shown that the side bearings will foul when the rate is greater than $1\frac{1}{2}$ in. to 33 ft., and the limit established provides for only $\frac{1}{2}$ in. defect in surface.

Limited-Speed Track—When a short run-off must be used, and the speed is limited, a practical run-off is obtained by making the elevation at the natural point of curve one-half the full elevation. The point of full elevation will then occur 30 ft. to 50 ft. beyond the point of curve, and the point of no elevation will occur 30 ft. to 50 ft. back of the point of curve. The elevation of the middle point back of the point of curve should be slightly less than one-fourth the full elevation, and that beyond the

point of curve slightly more than three-fourths the full elevation. This will make the profile of the elevated rail a vertical reversed curve and render the run-off quite as easy for moderate speed as the longer run-off is for high speed.

An example of a short run-off for a 2 deg. curve with $1\frac{1}{2}$ in. elevation, to be operated at 40 miles per hour, is as follows: 0, level; 0+20, $\frac{1}{4}$ in.; 0+40 (P. C.), $\frac{3}{4}$ in.; 0+60, $1\frac{1}{4}$ in.; 0+80, $1\frac{1}{2}$ in.

11. SUPERELEVATION OF BODY OF CURVES.

The maintenance of line on curves is dependent upon a proper selection of superelevation both for the body of the curve and for the easements. It is not possible to make a formula that will apply alike to all variations of curvature, for any theoretical formula would apply only to the *ideal curve*. The ideal curve is the one of greatest radius, or least degree of curvature, wherein the slight changes due to shifting under traffic are of minimum effect. For high-speed main lines this is about 0 deg. 45 min. and for branch lines about 1 deg. 30 min.

The distortion of a curve through traffic shifting becomes greater as the degree of curve decreases. Since superelevation should be adjusted to the curvature that actually exists, manifestly a curve should have the superelevation that would be proper for the highest degree that might in fact be found, instead of that which would be selected to suit the assumed degree of the curve. Greater elevation is therefore required by the lighter curves

than that determined by the theoretical formula of mechanics.

Similarly, there is less superelevation needed for the sharper curves than the theoretical formula would indicate, because curves sharper than the ideal suffer relatively less distortion under traffic than lighter ones, and also because of the destructive effects from the slower traffic when the superelevation is excessive for such movement, and especially from theoretical considerations outlined in the next paragraph.

Since the centrifugal force acts horizontally and the component of this force along the plane of the top of the rails diminishes as the degree of curve (and with it the superelevation) increases; and since, from the fact of the car body being pivoted on supports near its ends, its center of gravity is deflected inward, which deflection increases as the degree of curve increases; and since the component of the centripetal force, which is developed by the weight of the car and is the force tending to deflect the car inward, increases with the degree of curve, there is therefore by theory as well as experience relatively less superelevation necessary for equilibrium as the degree of curve increases.

Rule for Superelevation—An empirical rule has been found which satisfies the requirements referred to and which has been amply tested in practice. Its usefulness depends upon the employment of the actual measured degree, and not the some-

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times incorrectly recorded degree, and presumes maintenance with reasonable fidelity.

In the table of superelevations there is shown a series of arcs between 0 deg. 15 min. and 2 deg., in which the members increase progressively, the

TABLE OF SUPERELEVATIONS.

Degree	Constant	Theo. Elev.	Prac. Elev.	Max. Speed
15 min.	10	$\frac{3}{4}$ in.	1 in.	70 miles per hour
20 min.	9	1 in.	$1\frac{1}{2}$ in.	70 miles per hour
30 min.	8	$1\frac{1}{2}$ in.	2 in.	70 miles per hour
45 min.	7	$2\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	70 miles per hour
1 deg. 05 min.	6	$3\frac{1}{2}$ in.	3 in.	70 miles per hour
1 deg. 30 min.	5	5 in.	$3\frac{1}{2}$ in.	70 miles per hour
2 deg. 00 min.	4	$6\frac{1}{2}$ in.	4 in.	70 miles per hour
2 deg. 30 min.	4	$7\frac{1}{2}$ in.	$4\frac{1}{2}$ in.	68 miles per hour
3 deg. 00 min.	4	$(8\frac{1}{2})$ in.	5 in.	65 miles per hour
3 deg. 30 min.	4	(9) in.	$5\frac{1}{2}$ in.	63 miles per hour
4 deg. 00 min.	4	(10) in.	6 in.	61 miles per hour
4 deg. 30 min.	4	$(10\frac{3}{4})$ in.	$6\frac{1}{2}$ in.	60 miles per hour
5 deg. 00 min.	4	$(11\frac{1}{2})$ in.	7 in.	59 miles per hour

TABLE OF PRACTICAL ELEVATIONS.

Degree	70	65	60	55	50	45	40	35
0° 15'	1	1	-----	-----	-----	-----	-----	-----
0° 20'	$1\frac{1}{2}$	-----	1	-----	-----	-----	-----	-----
0° 25'	-----	$1\frac{1}{2}$	-----	1	-----	-----	-----	-----
0° 30'	2	-----	$1\frac{1}{2}$	-----	1	-----	-----	-----
0° 35'	-----	2	-----	$1\frac{1}{2}$	-----	1	-----	-----
0° 45'	$2\frac{1}{2}$	2	-----	$1\frac{1}{2}$	-----	1	-----	-----
0° 55'	-----	$2\frac{1}{2}$	2	-----	$1\frac{1}{2}$	-----	1	-----
1° 05'	3	-----	$2\frac{1}{2}$	2	$1\frac{1}{2}$	-----	1	-----
1° 30'	$3\frac{1}{2}$	3	$2\frac{1}{2}$	-----	2	$1\frac{1}{2}$	-----	1
2° 00'	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	-----	$1\frac{1}{2}$	1
2° 30'	5	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	-----	$1\frac{1}{2}$
3° 00'	-----	5	-----	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	$1\frac{1}{2}$
3° 30'	-----	-----	5	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2
4° 00'	-----	-----	-----	5	4	$3\frac{1}{2}$	$2\frac{1}{2}$	2
4° 30'	-----	-----	-----	-----	$4\frac{1}{2}$	$3\frac{1}{2}$	3	$2\frac{1}{2}$
5° 00'	-----	-----	-----	-----	5	4	3	$2\frac{1}{2}$
5° 30'	-----	-----	-----	-----	-----	$4\frac{1}{2}$	$3\frac{1}{2}$	3
6° 00'	-----	-----	-----	-----	-----	5	4	3
6° 30'	-----	-----	-----	-----	-----	-----	$4\frac{1}{2}$	$3\frac{1}{2}$
7° 00'	-----	-----	-----	-----	-----	-----	5	4
7° 30'	-----	-----	-----	-----	-----	-----	-----	4
8° 00'	-----	-----	-----	-----	-----	-----	5	-----

first increment being 5 min. and each succeeding increment 5 min. greater than the preceding one. Opposite the smallest arc is placed the constant 10, which represents so many ten-thousandths, and in

inverse order the numerals down to 4, which applies to the largest arc in the series and to all curves above 2 deg.

The proper superelevation in inches is obtained by multiplying together the square of the limiting speed in miles per hour, the degree of the curve and the constant that applies, the nearest half-inch being used in the final result.

The theoretical elevations in the appended table were obtained by the use of the constant 6.6 for all the degrees of curvature. This constant is derived directly from the formula in mechanics, and is in rather common use. The practical elevations were obtained by the use of the several constants shown. The apparent variance in result for the higher degrees of curvature really does not exist, since it is customary to assume a lower rate of speed in figuring for the sharper curves; but clearly such practice is objectionable because it lacks uniformity. The empirical rule requires only that the limiting speed shall be employed, which will always be fixed by time-table rule. While the maximum speed alone was used in the making of the first of the two tables, it will be found that the empirical rule furnishes equally satisfactory results for all speeds. The second table shows the proper superelevations in inches for various degrees of curve and for different limiting speeds in miles per hour.

Effect of Traffic—In determining the question of superelevation full consideration should be given the needs of the more important traffic. It may

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sometimes be preferable, in the case of heavy-tonnage freight lines, to establish the superelevation with reference to the slow traffic and limit the movement of passenger trains or light engines to the same rate of speed. On main lines carrying not only high-speed passenger trains, but a considerable number of freight trains, it is usual to confine the freight traffic to separate tracks; but as these tracks must sometimes be used for passenger trains, a balance is obtained by restricting somewhat the speed of the former and increasing that of the latter as much as possible.

12. ANALYSIS OF LINING AND ELEVATION CORRECTION.

Example 11 is intended to show the application of all the above methods in practice. The tangent offsets have been computed for the average of the curvature between each two adjoining stations, as obtained from the respective middle ordinates of those stations. It will be seen that in both easements the several offsets are in the approximate ratios of the cubes of successive numerals, between 1 and 7 for the longer easement and 1 and 5 for the shorter one. This satisfies the requirements of the curve known as the *cubic parabola* considered as being referred to coördinate axes. It will further be noted that the arcs shown as average degree, which are twice the deflection angles of the curve, are in the ratios of the squares of successive numerals. This is a geometrical condition of the same

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curve, and it is thus shown that the spiral whose ordinates increase progressively is the cubic parabola. This curve has long been regarded as the most efficient of all easement curves.

A comparison of the computed elevations with those that would conform with a regular rate of increase, confirms the correctness of the empirical rule for superelevation. It will be noted that the practical elevations are a mean of the computed elevations on either side, as is proper from due consideration of mechanical forces applied to a moving railway car. The limiting speed for the curve should be 65 miles per hour, and this requires that the 3 deg. curve should have 5 in. elevation and the 1 deg. 50 min. curve $3\frac{1}{2}$ in. elevation.

The curve of the spiral on the approach between Sta. 2 and Sta. 4+50 increases in a regular progression by increments of $6\frac{1}{2}$ min. multiplied by the numerals between 1 and 7; and the corresponding ordinates increase regularly by increments of $\frac{9}{32}$ in. multiplied by the same numerals, 1 to 7. The curvature of the spiral between the two curves Sta. 7+50 to Sta. 8+50, increases by increments of 1, 2 and 3 times 12 min. respectively, while the ordinates increase by 1, 2 and 3 times $\frac{9}{16}$ in. The curvature of the spiral on the run-off between Sta. 12+50 and Sta. 14 increases by 1 to 5 times $7\frac{1}{2}$ min., while the ordinates increase by 1 to 5 times $\frac{5}{16}$ in. These features further confirm the curves as the cubic parabola. The rates of change in curvature coördinate satisfactorily with the rates of

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Final Ordinate	Degree	Average Degree	Tan. off.	Theo. Elev.	Actual Elev.
4	06'	03'	.047	$\frac{1}{2}$	$\frac{1}{2}$
7	20'	13'	.33	$\frac{1}{8}$	$\frac{1}{8}$
18	38'	29'	1.23	2	2
28	1° 05'	52'	3.26	$2\frac{1}{2}$	$2\frac{1}{2}$
44	1° 37'	21'	6.80	$3\frac{1}{4}$	$3\frac{1}{4}$
6	2° 16'	1° 56'	12.41	4	4
8	3° 00'	2° 38'	20.89	5	5
8	3° 00'			5	5
8	3° 00'			5	5
8	3° 00'			5	5
8	3° 00'			5	5
6 $\frac{1}{2}$	2° 25'			$4\frac{1}{2}$	$4\frac{1}{2}$
5 $\frac{5}{8}$	2° 03'			$4\frac{1}{2}$	$4\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
4 $\frac{3}{4}$	1° 50'			3 $\frac{1}{2}$	3 $\frac{1}{2}$
3 $\frac{3}{4}$	1° 12'	1° 30'	7.85	3 $\frac{1}{2}$	3
18	43'	57'	34.9	$2\frac{1}{2}$	$2\frac{1}{2}$
7	21'	32'	1.27	$1\frac{1}{2}$	$1\frac{1}{2}$
4	06'	03'	.047	$\frac{1}{2}$	$\frac{1}{2}$

Station	Original Ordinate	Solution		
2	0	1	7	18
2+50	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$	27
3	$\frac{1}{4}$	2	2 $\frac{1}{4}$	44
3+50	4	4	4	6
4	$4\frac{1}{4}$	5 $\frac{5}{8}$	5 $\frac{5}{8}$	8 $\frac{1}{2}$
4+50	$5\frac{1}{4}$	6	6	8 $\frac{1}{2}$
5	8	8 $\frac{1}{2}$	8 $\frac{1}{2}$	8 $\frac{1}{2}$
5+50	$8\frac{3}{4}$	9	9	8
6	$8\frac{1}{2}$	7 $\frac{1}{2}$	7 $\frac{1}{2}$	7 $\frac{1}{2}$
6+50	$8\frac{1}{4}$	8 $\frac{1}{4}$	8 $\frac{1}{4}$	
7	$8\frac{1}{2}$	8 $\frac{1}{2}$	8 $\frac{1}{2}$	
7+50	$4\frac{3}{4}$	6 $\frac{1}{2}$	6 $\frac{1}{2}$	
8	6	4 $\frac{3}{4}$	4 $\frac{3}{4}$	
8+50	$4\frac{1}{2}$	4 $\frac{3}{4}$	4 $\frac{3}{4}$	
9	$4\frac{1}{2}$	3 $\frac{3}{4}$	3 $\frac{3}{4}$	
9+50	5	3 $\frac{1}{2}$	3 $\frac{1}{2}$	
10	$5\frac{1}{4}$	3 $\frac{1}{2}$	3 $\frac{1}{2}$	
10+50	$4\frac{3}{4}$	3 $\frac{1}{2}$	3 $\frac{1}{2}$	
11	5	3 $\frac{1}{2}$	3 $\frac{1}{2}$	
11+50	$4\frac{1}{2}$	3 $\frac{1}{2}$	3 $\frac{1}{2}$	
12	$5\frac{1}{4}$	2 $\frac{1}{2}$	2 $\frac{1}{2}$	
12+50	$2\frac{1}{2}$	1 $\frac{1}{2}$	1 $\frac{1}{2}$	
13	2	1	1	
13+50	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	
14	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	

Example 11. Lining and Superelevation Corrections.

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change in superelevation, which are $1\frac{1}{4}$ in. to 100 ft. on the ends, and 1 in. to 100 ft. between the curves.

It will be noted in this example that the supplementary rule which supplies the relation of error to correction is equally applicable to the easements, the only difference being that instead of a mean ordinate being used, the proper final ordinates at the respective stations are used.

The average error of this example before treatment was 12 per cent, which would not be bad but for the fact that two-thirds of the error occurs at three points, which it is interesting to note are in each case within the easements. Sta. 3+50 and Sta. 7+50 are especially bad, and the easement Sta. 12+50 to Sta. 14 is generally deficient.

CHAPTER V.

THE SPIRAL.

13. THE SPIRAL BY MIDDLE ORDINATES.

As the string method of lining the body of curves has replaced the instrumental method, so also will the former method be found preferable for establishing the easement at the ends of curves or between the parts of a compound curve. The spiral, which is desirable from the beginning, but is actually indispensable when the new railroad has settled and become fit for high-speed operation, is a refinement which is rarely provided in the original location, and it must be obtained in the course of maintenance by readjustment to some extent of the body of the curve.

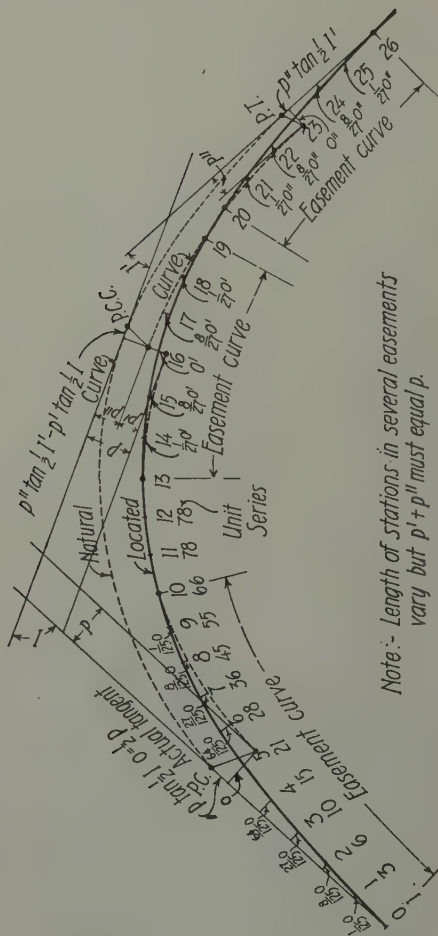
The prime requisite in the design of a spiral is that it shall be in proper relation with the run-off of the curve, which in turn is dependent upon the amount of superelevation and its rate of decrease. This rate, stated previously in a general way, may be established for high-speed service somewhat as follows: for curves under 45 min., $\frac{1}{4}$ in. to 33 ft.; between 45 min. and 3 deg., $\frac{1}{3}$ in. to 33 ft.; over 3 deg., $\frac{1}{2}$ in. to 33 ft.; and for slower speeds, not to exceed 1 in. to 33 ft. While it is not always practicable, especially for the sharper curves, to obtain the exact spiral desired, there are certain principles which should be satisfied as far as possible. The

important part of a spiral is the portion which connects with the main curve or, in the case of a compound curve, with the sharper curvature.

The ideal ordinates of the spiral curve should be adhered to through two-thirds of its length, or generally to the point where $1\frac{1}{2}$ in. or less of super-elevation obtains. Beyond that point the spiral admits of some modification, and may be made more flat if desired or if necessary in order to extend it to the point of no elevation.

The Unit Series for Designing the Spiral—In the spirals of Example 11 it was observed that the tangent offsets varied as the cubes of successive numerals, and the deflection angles varied as the square of the distance, which are characteristics of the cubic parabola. It may be shown that these conditions are present in all spirals whose members increase by successive increments, which are themselves in arithmetical progression. Thus, the series 1, 3, 6, 10, 15, 21 in., etc., in which the maximum number of units is 6 and the value of the unit 1 in. may be taken as an example. The curvature between any two adjacent stations would be represented by a mean of the ordinates, the series indicating the curvature thus becoming $\frac{1}{2}$, 2, $4\frac{1}{2}$, 8, $12\frac{1}{2}$ and 18 in., in which it is seen that the ratios of the several members to the first are the squares of successive numerals; the ratio of 2 to $\frac{1}{2}$ being 4, which is the square of 2, the ratio of $4\frac{1}{2}$ to $\frac{1}{2}$ being 9, the square of 3, etc.

The unit series extended as far as may be neces-



Note:- Length of stations in several easements
vary but $p' + p''$ must equal p .

Fig. 2. Spirals by Offsets, and Unit-Series Ordinates.

sary is especially useful in designing an easement for the sharper curves, and its employment in the design of any easement reduces to a minimum the labor required. The value of the unit will be obtained by dividing the ordinate of the body of the curve by the highest member of the series found practicable of application. The several ordinates of the easement will be obtained by multiplying each member of the series by the value of the unit. Thus, if the ordinate is 8 in. and 5 stations of easement are found possible, dividing 8 in. by 21 gives $\frac{3}{8}$ in. as the value of the unit; and the several ordinates of the easement are found to be $\frac{3}{8}$ in., $1\frac{1}{8}$ in., $2\frac{1}{4}$ in., $3\frac{3}{4}$ in., $5\frac{5}{8}$ in.

Length of String for $\frac{1}{8}$ Spiral—In the solution of most problems of main line curves operated at the highest speed and requiring the longest easement possible, it will generally be found preferable to adapt the length of string to the particular curve that is being investigated. In such cases the $\frac{1}{8}$ spiral furnishes an ideal solution. The series in which the value of the unit is $\frac{1}{8}$ in. is as follows: $\frac{1}{8}$, $\frac{3}{8}$, $\frac{3}{4}$, $1\frac{1}{4}$, $1\frac{7}{8}$, $2\frac{5}{8}$, $3\frac{1}{2}$, $4\frac{1}{2}$, $5\frac{5}{8}$, $6\frac{7}{8}$, $8\frac{1}{4}$ in., etc.

By proper choice of a length of string the ordinate of the body of the curve may be made to coincide with the number of this series, which will furnish the desired or practical length of easement. If for any reason it is necessary or desirable to use a different length of string than will provide this agreement, it is only necessary to change the value

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Degree	Ordinate	Chord	Max. No. Units	Length ease- ment equals superelevation Times speed	Rate of decrease in Run-off	Degree	Ordinate	Chord	Max. No. Units	Length ease- ment equals superelevation Times speed	Rate of decrease in Run-off
0° 20'	$\frac{3}{4}$	93	3	$93 = 1\frac{1}{2} \times 62$	$\frac{1}{4}$ in 33'	1° 30'	$1\frac{7}{8}$	67	5	$134 = 3\frac{1}{2} \times 40$	$\frac{1}{2}$ in 33'
0° 30'	$1\frac{1}{4}$	100	4	$150 = 2 \times 75$	$\frac{1}{4}$ in 33'	2° 00'	$2\frac{5}{8}$	70	6	$175 = 4 \times 45$	$\frac{1}{2}$ in 33'
0° 45'	$1\frac{7}{8}$	98	5	$196 = 2\frac{1}{2} \times 78$	$\frac{1}{4}$ in 33'	2° 30'	$3\frac{1}{2}$	73	7	$219 = 4\frac{1}{2} \times 49$	$\frac{1}{2}$ in 33'
1° 05'	$2\frac{5}{8}$	96	6	$240 = 3 \times 80$	$\frac{1}{3}$ in 33'	3° 00'	$4\frac{1}{2}$	76	8	$266 = 5 \times 53$	$\frac{1}{2}$ in 33'
1° 30'	$3\frac{1}{2}$	94	7	$282 = 3\frac{1}{2} \times 80$	$\frac{1}{3}$ in 33'	3° 30'	$5\frac{5}{8}$	78	9	$312 = 5\frac{1}{2} \times 57$	$\frac{1}{2}$ in 33'
2° 00'	$4\frac{1}{2}$	92	8	$322 = 4 \times 80$	$\frac{1}{3}$ in 33'	4° 00'	$6\frac{7}{8}$	80	10	$360 = 6 \times 60$	$\frac{1}{2}$ in 33'
2° 30'	$5\frac{5}{8}$	92	9	$368 = 4\frac{1}{2} \times 82$	$\frac{1}{3}$ in 33'	4° 30'	$8\frac{1}{4}$	82	11	$410 = 6\frac{1}{2} \times 63$	$\frac{1}{2}$ in 33'
1° 05'	$1\frac{7}{8}$	82	5	$164 = 3 \times 55$	$\frac{2}{5}$ in 33'	2° 00'	$1\frac{7}{8}$	60	5	$120 = 4 \times 30$	$\frac{5}{8}$ in 33'
1° 30'	$2\frac{5}{8}$	82	6	$205 = 3\frac{1}{2} \times 59$	$\frac{2}{5}$ in 33'	2° 30'	$2\frac{5}{8}$	63	6	$158 = 4\frac{1}{2} \times 35$	$\frac{5}{8}$ in 33'
2° 00'	$3\frac{1}{2}$	82	7	$246 = 4 \times 62$	$\frac{2}{5}$ in 33'	3° 00'	$3\frac{1}{2}$	66	7	$198 = 5 \times 40$	$\frac{5}{8}$ in 33'
2° 30'	$4\frac{1}{2}$	83	8	$290 = 4\frac{1}{2} \times 64$	$\frac{2}{5}$ in 33'	3° 30'	$4\frac{1}{2}$	70	8	$245 = 5\frac{1}{2} \times 45$	$\frac{3}{4}$ in 33'
3° 00'	$5\frac{5}{8}$	84	9	$336 = 5 \times 67$	$\frac{2}{5}$ in 33'	4° 00'	$5\frac{5}{8}$	73	9	$296 = 6 \times 50$	$\frac{9}{16}$ in 33'
3° 30'	$6\frac{7}{8}$	86	10	$387 = 5\frac{1}{2} \times 70$	$\frac{2}{5}$ in 33'	4° 30'	$6\frac{7}{8}$	77	10	$385 = 6\frac{1}{2} \times 53$	$\frac{1}{2}$ in 33'
4° 00'	$8\frac{1}{4}$	88	11	$440 = 6 \times 73$	$\frac{2}{5}$ in 33'	5° 00'	$8\frac{1}{4}$	80	11	$400 = 7 \times 57$	$\frac{7}{16}$ in 33'

Table of Spiral Functions.

THE SPIRAL

of the unit to some multiple of $\frac{1}{8}$ in., which is found by obtaining the ratio of the square of the chord used to the square of that which would be ideal.

Use of the Table of Spiral Functions—A table has been prepared which gives the computed values of the functions pertaining to certain curves which can be extended by offhand interpolations to include all curves. The question of superelevation and rate of decrease having been established for the known degree of curve, the proper length of string may be selected from the table for use in making a study of the curve and for designing the easement. Or, conversely, the table may be used to determine the value of the unit when a different length of string is used.

ONE-EIGHTH SPIRALS FOR HIGH SPEED OPERATION.

(Run-Off 1" to 100'—Chord 100'.)

Superelevation	$1\frac{1}{2}"$	2"	$2\frac{1}{2}"$	3"	$3\frac{1}{2}"$
Degree of Curve.....	20'	30'	45'	1°05'	1°30'
Point of Full Elevation..	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{5}{8}$	$3\frac{5}{8}$
Point of Full Ordinate....	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{5}{8}$	$3\frac{5}{8}$
End of Spiral.....	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{5}{8}$
	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{8}$
		$\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$
			$\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{4}$
				$\frac{1}{8}$	$\frac{3}{8}$
					$\frac{1}{8}$

SPIRALS FOR 350 FT. RUN-OFF.

(Chord 100'.)

Speed	70	70	65	55	50
Superelevation	3"	4"	5"	5"	5"
Degree of Curve.....	1°	2°	3°	4°	5°
Point of Full Elevation..	$2\frac{5}{8}$	$5\frac{1}{4}$	$7\frac{7}{8}$	$10\frac{1}{2}$	$13\frac{1}{8}$
Point of Full Ordinate....	$2\frac{5}{8}$	$5\frac{1}{4}$	$7\frac{7}{8}$	$10\frac{1}{2}$	$13\frac{1}{8}$
End of Spiral.....	$1\frac{7}{8}$	$3\frac{3}{4}$	$5\frac{5}{8}$	$7\frac{1}{2}$	$9\frac{3}{8}$
	$1\frac{1}{4}$	$2\frac{1}{2}$	$3\frac{3}{4}$	5	$6\frac{1}{4}$
	$\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{4}$	3	$3\frac{3}{4}$
	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{7}{8}$
Beginning of Spiral.....	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
Rate of Run-Off 1" in	117'	$87\frac{1}{2}'$	70'	70'	70'

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SPIRALS FOR 217 FT. RUN-OFF.

(Chord 62'.)

Speed	48	46	44	42	40
Superelevation	3½"	4"	4½"	5"	5½"
Degree of Curve.....	4°	5°	6°	7°	8°
Point of Full Elevation..	4	5	6	7	8
Point of Full Ordinate....	4	5	6	7	8
End of Spiral.....	2¾	3⅝	4⅛	4⅞	5⅝
	1⅞	2½	2⅞	3¼	3¾
	1⅞	1½	1¾	2	2¼
	½	¾	⅞	1	1⅞
Beginning of Spiral.....	¼	¼	¼	⅜	⅜
Rate of Run-Off.....	1" in 60'	54'	48'	43'	40'

Thus, in Example 11, a chord of 100 ft. was used for the 3 deg. portion of the compound curve as well as for the 1 deg. 50 min. portion; and the maximum number of units found practical for the desired easement of the 3 deg. curve was 7. By reference to the table it is found that the chord corresponding to a maximum of 7 units is 66 ft. The proper value of the unit is found by multiplying $\frac{1}{8}$ in. by the ratio of $(100)^2$ to $(66)^2$, and it thus becomes $\frac{9}{32}$ in.

As another illustration, a perfect spiral between a 3 deg. curve and a 0 deg. 20 min. curve would be obtained by the use of a 92 ft. string, when the ordinate of the sharper curve would be the tenth member of the series and of the flatter curve the third member. The 7 stations of easement, equivalent to 9 stations of run-off, allow a decrease in elevation between the 5 in. for the 3 deg. curve and the $1\frac{1}{2}$ in. for the 0 deg. 20 min. curve, of $\frac{1}{3}$ in. in 33 ft. But it might not be practicable to apply the preferred easement and the one attainable

might only permit of a run-off at the rate of $\frac{1}{2}$ in. in 33 ft., which is the extreme limit for high-speed operation. This would require that a 66 ft. string be used, and the ordinate of the sharper curve would become the 7th member of the series, and of the flatter curve the second member; and the length of easement thus would be reduced 2 stations. Any further reduction in the length of easement would require a greater reduction in speed.

Examples of Spirals—A typical spiral is given for several light curves in high-speed operation; for several average main-line curves with moderate run-off; and for several sharp curves with minimum rate of run-off for branch operation.

While the design of the spiral is only indirectly related to the speed, and similarly no arbitrary length of easement for certain groups of curvature is practicable, these functions have been included in the table for the convenience of those who may prefer to give them consideration.

14. THE SPIRAL BY THE INSTRUMENT.

The type of easement that is most suitable for general use is one that can be readily designed for application with the instrument, and easily maintained by string lining. The cubic parabola fulfills both requirements. While the engineer may reasonably claim that it generally is an unnecessary refinement to stake out the detailed spiral curve in the preliminary location, it cannot be denied that provision should be afforded for such adjustment, and a

knowledge of the practical working limits, as derived by a careful study of the operating requirements, becomes important.

Staking out the Curve between Offset Tangents—A simple method for applying the easement curve by the instrument is as follows: Stake out the circular curve as between imaginary tangents parallel to, and a selected distance within, the lines of the actual tangents; shorten the circular curve on each end by the half length of the easement, and locate points on the actual tangents at the same distance in the opposite direction; relocate the stakes marking the original ends of the circular curve a distance outward equal to one-half the selected offset distance. This location will enable the track-laying forces to adjust the curves by eye with sufficient precision for the purpose of the new construction and will allow of the final detailed adjustment being made later with nominal expense.

Relation of Offset to Length of Spiral—The amount of the offset will depend upon the length of easement desired, and this in turn will be governed by feasibility and the service required. The least offset of practical utility is one whose length in tenths of a foot is equal to the figure representing the degree of curve, and this will provide an easement curve with the half length equal to 60 ft. If a longer easement curve is desired and is not impracticable, the offset distance should be increased in the ratio of the squares of the half-lengths.

For a very satisfactory adjustment upon a branch

of medium traffic requirements, the half-length of easement might be made 75 ft., and the offset distance would then be the number of tenths of a foot equal to $1\frac{1}{2}$ times the figure for the degree of curve. If a run-off at a rate of $\frac{1}{2}$ in. to 30 ft. were desired for a 4 deg. curve, operated at 40 miles per hour, with a superelevation of 3 in. attained 60 ft. upon the circular curve, the half-length of 60 ft. would be proper, and the offset distance would be 0.4 ft.; but if the same curve were part of an important main line route to be operated at 55 miles per hour, and the rate of the run-off necessary for the 6 in. superelevation were desired to be 1 in. to 100 ft., a half-length of 250 ft. would be required and the offset distance would be 7 ft.

Staking out the Easement Curve by Offsets—In the latter case it would be necessary to stake out the entire easement curve, preferably by 50-ft. stations, and the above described methods would apply; or, if preferred the location might be made by offsets, for one-half the easement curve from the actual tangent, and for the other half by similar offsets from the original circular curve. With this method equal stations could be used, when the several offsets would be the proportion of that at the middle of the easement determined by the cube of their relative distance from the ends of the easement. Thus, in the case cited, the first offset would be $1/125$ th of 3.5 ft. or 0.028 ft., and the several other offsets, respectively, 8, 27 and 64 times this, or 0.22 ft., 0.76 ft., and 1.79 ft.

The same methods would of course apply to the easement between two curves of considerably different curvature. The offset distance between the imaginary tangents at the P. C. C. would then be computed from the difference in the numbers representing the degree of the two curves. The several offsets would be measured from the two circular arcs. The unit middle ordinate would be obtained by dividing the difference between the ordinates of the two curves by the highest number of the series applicable. The spiral ordinates then obtained would each be increased by the amount of the ordinate of the lighter curve.

15. THE ADVANTAGE AND COST OF SPIRALING CURVES.

Early Location Made Without Easements—It was universally the practice in the early days of railroads, as it very generally is today, to locate a line as a succession of tangents with no provision for present or future easements. Although operation is possible over such an alinement it must necessarily be at a very moderate speed, and even then accidents are of not infrequent occurrence. While locomotives were small and the greatest speed attainable was comparatively slow, the lack of easements for the lighter curves was not felt; but their absence from the sharper curves was always a source of trouble. Indeed, it is difficult to conceive how operation was otherwise than precarious upon many such curves that were devoid of easements. The presence of superelevation pre-

supposes curvature and the very fact of a tangent track being several inches out of level, whether at the approach to a curve or elsewhere, suggests the possibility of accident. The records of most branch roads contain the accounts of derailments occurring at the ends of curves, the causes of which were never satisfactorily ascertained. But the fact is pertinent that such accidents become noticeably fewer following the proper spiraling of the curves. With the increase of speed in both passenger and freight schedules the addition of easements has become not merely a refinement for comfort, but a necessity for safety.

Making Easements on Old Lines—Various methods have been used in providing present easements on old lines. The first was usually to throw the ends of the curve outward, which served to remedy part of the defect, though the resulting protrusions beyond the tangents were both unsightly and to some extent uncomfortable. When adjoining curves turned in the same direction and the tangent between was short, it readily appeared that a relining of the entire tangent would effect the necessary correction; although in most cases the protrusion was allowed to remain as the lesser of two evils.

As methods were evolved for the lining of curves the flat places developed by the outward throw of the ends were eliminated by lining the entire body of the curve inward, the throw being often as much as 6 in. Finally, when such methods, at first crude, were further improved, complete adjustment was

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made on exact lines, the protrusions being removed, a more efficient easement provided and finer detail line of the curve attained. The last adjustment nearly always consisted in making, first, an inward throw of the ends, designed to remove the protrusions, which makeshift correction and the distorting action of the traffic had produced, and also to flatten the curve for the easements; and second, an outward throw throughout the entire remaining body of the curve, varying in amount from 2 in. to 6 in., to absorb the sharp places which the preceding throws had introduced at each extremity of the remaining arc. The net result of the several changes was a lengthening of the curve amounting to about 75 feet on each end and a sharpening of the circular arc about 3 per cent of the initial degree.

Providing for Easement in Original Location—As affecting the question of introducing easements into the original location, or at least of providing the means for such correction at a later time when the roadbed shall have settled, it will be instructive to study the cost of the relining necessary to attain this end when no such provision has been made. It will no doubt be thought that the value of the labor thus spent is so indefinite as to be impossible of even approximate estimation. But the record of cost on a typical branch road of medium traffic and maintenance is offered as a suitable criterion. The road, which is cinder ballasted, is 44 miles in length and the speed prescribed is 40 miles per hour. The alinement follows the shore of a river through all

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its points and bays, and contains 185 curves, several as sharp as 8 deg., the average of all being 3 deg. 20 min. It is safe to say that each has had the three general lining adjustments referred to during the 20 years of the road's operation, and a conservative estimate of the total cost of the several adjustments is approximately 10c per foot of curve. For this road, on which the curves compose 57 per cent of the total length, the expense of adjustment was \$300 per mile of single track line. The labor necessary for spiraling the curves thus amounted to no less than \$13,000, a considerable sum of which would unquestionably have been largely saved if ultimate addition of easements had been provided for in the original alinement.

CHAPTER VI.

THE VERTICAL CURVE.

16. THE USES OF THE VERTICAL CURVE IN MAINTENANCE.

The subject of vertical curves, which is discussed in this chapter, is not strictly a part of the general theme of curve adjustment, but concerns rather the adjustment of gradients. It is, however, a very important feature in track maintenance and one which is not always given the attention it deserves. Adjustments by the vertical curve are handled by the engineer, and this subject is therefore of little interest to the track foreman.

The method of designing the vertical curve as a parabola is explained in the several field books, and is probably in quite common use. Its utility in modifying the sharp change at a grade intersection is generally recognized; but its advantage in replacing a succession of short, straight grades of continually changing inclination may not be so fully appreciated. It is just as necessary that the vertical changes in motion shall be effected smoothly as that the horizontal changes in direction shall be made by means of regular curves.

Rate of Change—The importance of the vertical deflections is well shown by the case of the run-off. In times past a rate of $\frac{1}{2}$ in. to 30 ft. was nearly universal. It is now recognized that the maximum

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of comfort obtains when a run-off of one-half this inclination is employed. Somewhat similar principles enter into the design of a vertical curve, and the proper length of curve to afford an easy passage over a summit or across a depression is obtained by an application of the features common to the run-off.

Continuous Vertical-Curve Gradient—The problem of establishing a new gradient to fit one that has been much distorted through years of track raising by the eye often presents two phases: one of establishing a number of short grades and one of merging the short grades into a continuous grade on a curved line. The essential feature in grade refinement is not that the grade shall be straight, but that it shall be *continuous*. This becomes of the greatest importance when the grade is coincident with an interlocking or an extensive switch layout.

The method given for computing vertical curves is of practical application to all grade intersections that are commonly met with in railway practice, and it can be employed for any length of vertical curve. The method has been applied in the case of a grade correction wherein a vertical curve a mile in length resulted. The method will be found equally advantageous in compromising the steep gradients sometimes required in siding layout.

Vertical curves are not employed in siding construction and maintenance to the extent their usefulness deserves, and many derailments may be traced to lack of this feature. When the mean of

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the elevation of two points 18 ft. apart differs more than 1 in. from the elevation of the point midway between them, a vertical curve is a necessity. The difficulty of introducing a vertical curve for a summit after the track is completed is of course appreciated.

17. COMPUTATION OF THE VERTICAL CURVE.

The simplest method of computing a vertical curve is the orthodox one in which (1) the correc-

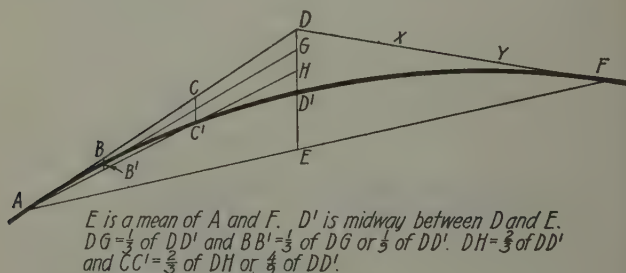


Fig. 3. Geometrical Principle of the Vertical Curve.

tion at the grade intersection is one-half the difference between the elevation of the intersection and a mean of the elevations of the assumed tangent points, and (2) the corrections at the other points are the fractions of the whole correction represented by the square of their fractional distance from the tangent points, the corrections being minus for a summit and plus for a depression.

The geometrical principles are illustrated in Fig. 3. The method is the more nearly exact the smaller

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the intersection angle of the grades; but this method is sufficiently accurate for all grades that are practical to railroads. Vertical reversed curves or compound curves follow the same general lines as simple vertical curves. In the case of the former the best arrangement is had by entirely eliminating the tangent common to both curves.

For vertical curves in high speed main lines the assumed tangent points should be so remote from the intersection that the correction 100 ft. from the tangent points will not exceed $1\frac{1}{2}$ in. It is desirable that where possible this correction shall be as little as $\frac{3}{4}$ in. A too sudden change is similar in effect to a run-off that is made at an excessive rate.

The practical limit for the adjustment of siding grades is determined by the length of wheel base of the locomotive operating over the siding. The vertical curve should be flat enough to make the middle ordinate, on a chord equaling in length the wheel base, as little as 1 in.

18. EXAMPLE OF A VERTICAL CURVE.

An example on somewhat similar lines to the figure will make the application of the principle entirely clear. Assume the grade A to D to be ascending 1.1 per cent and D to F, descending 0.1 per cent; and that the elevation of A is 91.0, of the intersection D, 94.3, and of F, 94.0. The elevation of the middle point of the chord, or the point E, will be a mean of the elevations at A and F, or 92.5. One-half the difference between this grade and the

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grade of the intersection will be equivalent to the middle ordinate of the vertical curve. The value thus obtained is 0.9 and this subtracted from the elevation of the intersection will give the elevation of the vertex of the curve, or 93.4. (If the vertical curve were a depression instead of a summit, the middle ordinate would have been added.)

The corrections at the several stations are obtained by dividing the correction at the middle, 0.9, by the square of the ratio of distance from the ends of the curve. Thus B is $\frac{1}{3}$ the whole distance from A, and the correction is $\frac{1}{9}$ of 0.9, or 0.1; C is $\frac{2}{3}$ the distance and its correction $\frac{4}{9}$ of 0.9, or 0.4. The tabular figures show the final results.

Station	Tangent Grades Elevation	Vertical Curve. Elevation.
A	91.0	91.0
B	92.1	92.0
C	93.2	92.8
D	94.3	93.4
X	94.2	93.8
Y	94.1	94.0
F	94.0	94.0

CHAPTER VII.

ECONOMICS OF CURVES.

19. ECONOMICS OF CURVE LOCATION.

Speed on Main and Branch Lines—Generally speaking, there are but two divisions of railways, main lines to be operated at the now almost universal maximum limit of 70 miles per hour, and branch lines to be operated at the commonly prescribed maximum of 40 miles per hour. Upon the former the passenger traffic is usually predominant; upon the latter the freight traffic. When the main line is burdened with a considerable freight traffic it is the rule for this traffic to be carried upon definitely assigned tracks; and since these tracks may frequently be required for passenger movement their adjustment must be coördinated with the average of the two speeds, or say 55 miles per hour. It is now fully recognized that enginemen cannot regulate speed closer than 10 per cent, except when speed indicators are provided; and that even with faithful maintenance, depressions of $\frac{1}{4}$ in. in main lines and of $\frac{1}{2}$ in. in branch lines and similar variations of alinement are unavoidable. The latter figures may therefore be considered the working limits for the purpose of this discussion.

Light Degree Curves Unfavorable—One of the most common errors in past location of main lines has been the endeavor to obtain too light a degree

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of curvature. Thus, 10 min. curves are sometimes used, 15 min. not unusual and 20 min. quite common. Experience has shown that a measurable increase in cost of maintenance attaches to such selections. The degree of curve may be considered as the number of inches a joint deflects from a cord held to contact at the two adjacent joints. The exact length of such a chord is 61 ft. 8 in., but the proposition will serve for illustration. For a 15 min. curve the deflection would be $\frac{1}{4}$ in., and such a curve would theoretically require a superelevation of $\frac{3}{4}$ in. If a joint on the high side should become $\frac{1}{4}$ in. low and through this cause shift outward $\frac{1}{4}$ in., as quite probably would be the fact, there would result a curvature twice as sharp as the normal degree, or 30 min., and the superelevation of $\frac{1}{2}$ in. would be wholly inadequate, since such a condition would require 2 in. This disadvantage is partly overcome by employing a superelevation somewhat greater than that determined by the theoretical formula of mechanics. For example, a practical superelevation of $1\frac{1}{2}$ in. is used for a 20 min. curve although theoretically no more than 1 in. is necessary.

If, however, the curve was 45 min. and the same errors should enter, the curvature would become 1 deg. and, if the proper superelevation of $2\frac{1}{2}$ in. had been used, the $2\frac{1}{4}$ in. obtaining would still be sufficient for the increased curvature. A curve of this degree may therefore be considered the ideal one, and both theory and practice will indicate that the

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desirable limit for the lighter curves is between 30 min. and 1 deg., with even closer limits between 40 min. and 50 min. to be preferred.

Maximum Curvature—The maximum limit of curvature for important main lines to be operated without speed reduction is 2 deg. 20 min., which requires 5 in. superelevation. This amount should be fixed as the limit of superelevation for high speed tracks, not because any more is unsafe, but by reason of the discomfort which results when a slower speed is used. If the speed should become less than 35 miles per hour at such a point the disadvantage in this respect would be quite marked, and the destructive effects would be greater as the speed was further reduced.

The determination of the practical limits for branch line location is made similarly, and these are in general three times those for main lines, or between 1 deg. 30 min. and 7 deg. The proper superelevation for a 45 min. curve at an authorized speed of 40 miles per hour is 1 in. If this should become $1\frac{1}{2}$ in. through the low side settling and the curvature thereby become as light as 15 min. a speed of 70 miles per hour would be required for comfort; and if by the high side settling the superelevation should become as little as $\frac{1}{2}$ in. and the curvature as sharp as 1 deg. 15 min., no more than 30 miles per hour would be permissible. In the case of a 1 deg. 30 min. curve, however, requiring $1\frac{1}{2}$ in. superelevation, a sharpening of the curve to 2 deg. by reason of the superelevation diminishing to 1 in.

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would not render the conditions unfavorable, and a flattening of the curve to 1 deg. with the superelevation increased to 2 in. would not introduce any element of discomfort.

As regards the maximum limit of 7 deg. for which a superelevation of $5\frac{1}{2}$ in., to provide for natural deficiencies of line and surface and to allow for a 10 per cent increase of speed, would be necessary where maintenance was of medium character, this limit is based mainly upon a practical knowledge that superelevation in excess of this figure is undesirable if not actually improper. When maintenance is of the best a curve as sharp as 8 deg. may be operated at a speed of 40 miles per hour; but a safer practice would be to restrict the speed to 35 miles per hour for which the limiting superelevation of $5\frac{1}{2}$ in. would then be correct.

Location of Grade Intersections—Another error in location, causing a serious disadvantage in maintenance that is reflected in operation, is the placing of a grade intersection at the end of a curve. This is especially troublesome upon lines of undulating profile and with numerous curves, and these features usually occur together. The problems of the easement and of the vertical curve are simple enough when considered separately, but when they are in combination a question results which is much too complicated for any but the accomplished physicist. While it is possible to effect a practical adjustment of such conditions, the future maintenance will severely try the ability of the most expert track

foreman. It is a matter of experience that no greater disadvantage to the riding qualities of a track can be found than a dip in the grade just at the end of a curve, and the same fact holds true in a less degree of a summit. It requires some sacrifice to adjust the line or the profile so that the two features will be separated, but the advantages in maintenance which result fully justify the correction. This question is of timely interest, because of the tendency in making a compensation of the gradient for curvature, to introduce the change exactly at the end of the curve, which in the process of refined adjustment become the center of the easement, and the error is thus cumulative.

Minimum Length of Tangents—When curves are provided with proper easements there is theoretically no need for any tangent between the curves, but with a due regard for the aesthetic requirement and economically because it provides for the addition of siding connections under more favorable conditions, tangents should be provided at proper intervals. The minimum length to satisfy both needs would be 400 ft.

Widening Centers on Curves—In view of the great importance of clearance, not only at the side but between adjoining train movements, it becomes quite essential that a factor be designed for widening the track centers on curves. Three elements enter into the question, viz.: the design of the equipment, the relative superelevation of the several tracks and the degree of maintenance. The maxi-

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mum truck centers may be assumed as the equivalent in length of the chord which furnishes a middle ordinate in inches equal to the degree of curve. The overhang at the end is generally the same as that at the middle and, as these two combine to decrease the clearance, it may be stated that ideally the correction should be 2 in. per degree. When adjoining tracks are operated at different maximum speeds requiring difference in superelevation, there should be a further allowance of three times this difference. If maintenance is good the extreme allowance for swaying might safely be made 1 in.; if only fair as much as 2 in. would be required. Thus, a well-maintained main line curve of 2 deg. 30 min., with inner tracks operated at 60, and outer tracks at 70 miles per hour, would require a correction of $10\frac{1}{2}$ in. in the track centers. Clearly the tracks could not be made parallel throughout as this would require a reverse at the ends. The proper solution of such a case would be to adjust the difference through the respective easements of the several tracks.

Special Curve Problems—With the advent of the high island platforms for passenger service a nice problem in curve economics is presented for solution. This structure is almost certain to occur either wholly or in part upon curves. It is, of course, essential that a uniform opening be established and maintained between the car and the platform. To attain this with the platform alined upon a regular curvature ending in the tangents requires

that a reverse be introduced into the track curve, which is not only unaesthetic but disadvantageous. The importance of this will be fully appreciated when it is considered that the difference in distance of track from platform between tangent and a 2 deg. 30 min. curve, with 1 in. superelevation for operation at 30 miles per hour, would be $3\frac{1}{2}$ in. Such protrusion would unquestionably cause a very deficient alinement. The trouble will be entirely avoided by introducing proper easement curves into the platform alinement, as well as that of the track.

20. ECONOMICS OF CURVE MAINTENANCE.

The order of correction for the various defects of curves which are in poor line throughout should be: First, a roughing-in of the line to render the test with the string more effectual; second, adjustment of the line after a careful study of the ordinates obtained; third, application of a proper superelevation, including the run-off, or correction of any deficiency that may be found in the existing superelevation; fourth, the re-gaging, which is readily apparent after the line rail has been made true; and fifth, a fine detail lining.

Correction of Line Defects First—The general correction of the line is nearly always the first operation, for the fine surface would be disturbed if the throws should be several inches, and in the event that the established superelevation were excessive for the curve when made regular, this amount of elevation might be necessary even for safety at

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points on the curve where sharp places exist. Further, the proper superelevation and its limits, and the approach and run-off can only be determined by the line study of the curve. A careful examination of the present features of the run-off is quite essential, as it is no unusual occurrence to find the run-off improperly located, sometimes as much as several hundred feet from where it should be.

Protrusions at Ends of Curve—A very common defect is the protruding of the ends of the curve outside the line of the tangents. This defect arises through the tendency of a curve to make its own easement, and through the invariable practice of maintainers lining out the ends of curves to obtain the advantage of an easement. It is found that when the curve is provided with proper easements in the relining, natural shifting ceases and there is no longer a tendency of the foreman to thus distort the line in endeavoring to make a seeming correction. The elimination of this defect should be one of the main considerations in the preliminary lining, as its presence precludes a proper adjustment of the line.

Line and Surface Interdependent—The physical requirements of the curve having been amply met in perfect alinement and correct superelevation, and the easement and run-off being in proper proportion and location, the supervisor and foreman are confronted with the duty of maintaining the excellence of these features. It is well known that each is correlated with the others. Perfect line will not con-

tinue if the surface becomes deficient; the surface breaks down more quickly when the line is allowed to deteriorate; and the easement and the run-off suffer if one or the other develops defects.

The maintenance of good surface is more necessary on curves than on tangents. A $\frac{1}{4}$ -in. variation in the level of a tangent, provided it is continuous, cannot be regarded as poor maintenance. Such a condition might exist for some time and its presence be undiscovered until a critical test was made with the level board. In ordinary practice no attempt would be made to level up a tangent track having no greater variation than this until a raise in face was being made, when, of course, the surface would be made true. But on curves such a defect would be immediately objectionable. While superelevation is generally chosen to the nearest half inch, it is quite desirable in the case of light curves that there should be excess rather than deficiency.

Selection and Maintenance of Superelevation—

Through past error of practice, many main-line curves are of light curvature, 20 min. being most common. Experience has shown that upon such curves, when used at high speed, a half inch of superelevation makes the difference between comfort and discomfort to the passenger. This difference being noticeable in the choice between two superelevations, the difference would be much more marked if, through breaking down of the surface, the established superelevation should vary in places as much as $\frac{1}{2}$ inch. Bad maintenance would be

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readily apparent both in the line and the surface.

Regularity of the superelevation is the most important element in curve maintenance. This requirement can only be attained by consistent supervision. The track foreman is ordinarily quite faithful in his use of the track level when surfacing is being done, but he is not so apt to carry his level with him to try his curves for this defect. If the surface of the rail sights properly, the track is, in his view, all right. A test under his eyes with the level is the best lesson that can be given.

Maintenance of Line—The line having been made correct, the maintenance of good surface is necessary to its remaining correct. But even with faithful maintenance there is a certain amount of slight shifting under the traffic, which cannot be controlled, and which requires periodical correction. If neglected these slight detailed defects soon increase to the extent of a general deficiency, and eventually the line of the curve is lost and another relining with the string is necessary. In no other feature of track work is the old saw regarding the stitch in time more aptly illustrated.

There is no permanent means of marking the correct line of a curve. Stakes are struck by dragging parts of cars and only slightly disturbed after which they are worse than useless. Steel pins, old rails, even stone monuments are disturbed by frost, and in any event their usefulness depends upon measurement with a varying tape line held in every position except the horizontal. Maintenance of the cor-

rect line by continued watchfulness is the better practice.

Short Sags—The correction of the short sags, often no more than two or three rail lengths in extent, is an important item in curve maintenance. These dips are unfavorable at any point, as they render fine lining impossible and, no matter how perfect the work with the level, their presence prevents fine results in surface. But they are particularly objectionable on curves. Doubtless in theory they cause no defect if symmetrical with the cross section. But the depressions in the two rails are seldom directly opposite and a rolling of the car is the inevitable result, which under extreme circumstances may become a lurch. They should be regarded as defects and carefully removed in the general surfacing program.

Raise in Face—A raise in face is periodically necessary for all main tracks, the intervals depending upon the kind of roadbed and the character of the traffic. When such raising is being done on curves, it is customary for the low rail to be selected as the grade rail, although a very distinct advantage may be gained by using the opposite rail. In raising tangents it is very desirable to raise both rails together and usually against the current of traffic. But on curves many foremen prefer to raise the high rail to a proper grade, introducing for the time being added superelevation, and to follow this by bringing the low rail to the required grade, and this procedure is

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usually the better one when the raise is no greater than 2 in.

Maintenance of Ties—The basic requirement for curve maintenance is an ample renewal of the cross-ties to provide a firm bearing at all times. Generous tie replacement is desirable in all kinds of road, but it is essential on curves. This is not alone needed for maintaining the gage, although that is the prime consideration, but it is also necessary for preserving the surface, which in turn contributes to permanence of the line. A main-line curve can hardly be considered adequate track for heavy service unless it is well tied, with each tie protected by a tie plate.

Correct Gage—The importance of correct gage on curves cannot be over estimated. The superelevation of a curve is of course adjusted to just one speed. If the movement is at a very much slower speed, the wheels will press against the inside rail; if faster, against the outside rail; in either case a variation in the gage becomes immediately noticeable. The tendency of every curve to spread can only be met by a full equipment of tie plates. No matter what type of tie plate is preferred, they should be provided with a shoulder to relieve somewhat the pressure against the outside spikes. The tie plate should carry a third spike, and on curves where required a fourth spike, to draw the plate close against the rail base and to help hold it in place.

When tie plates are applied the gage should be

made correct according to the standards of the road. The gage should only be widened when the curvature exceeds 10 degrees, and should never be made more than 4 ft. 9 in. The best means of detecting imperfect gage by a casual inspection, is to run the eye along both rails of the track. If an irregularity shows upon one rail and not upon the other, the trouble is surely in the gage. Even where the track is plentifully equipped with tie plates there is constant need of gage correction, and to this end it is the practice on many divisions to keep a gaging gang of three men constantly employed. If the leader of this gang is efficient, the gage correction may be made a means of correcting the detail line as well.

PART II—PRACTICAL SWITCH CONNECTIONS

CHAPTER VIII.

ESSENTIAL ELEMENTS IN THE DESIGN OF SWITCH CONNECTIONS.

21. ELEMENTARY PRINCIPLES.

There is a certain information essential to the correct installation of switch connections which it is necessary for the supervisor, and quite desirable for those of his foremen who must perform such work, to have at their instant command. The supervisor is required to lay out switch work on the ground when access to tables may not be possible, or to instruct his foreman when a resort to memoranda would be inappropriate. The track foreman cannot always have the benefit of the supervisor's guidance; and at any rate when equipped to proceed upon his own working knowledge he naturally feels a greater degree of interest in the undertaking. There are not a few track foremen who are quite resentful of the intrusion of detailed directions for specific cases, but who are entirely willing to be instructed in the general rules necessary for nice accomplishment. This is especially true of switch connections, for which, unfortunately, there is much misleading data extant. Heretofore only the mathematically educated have been able to solve the va-

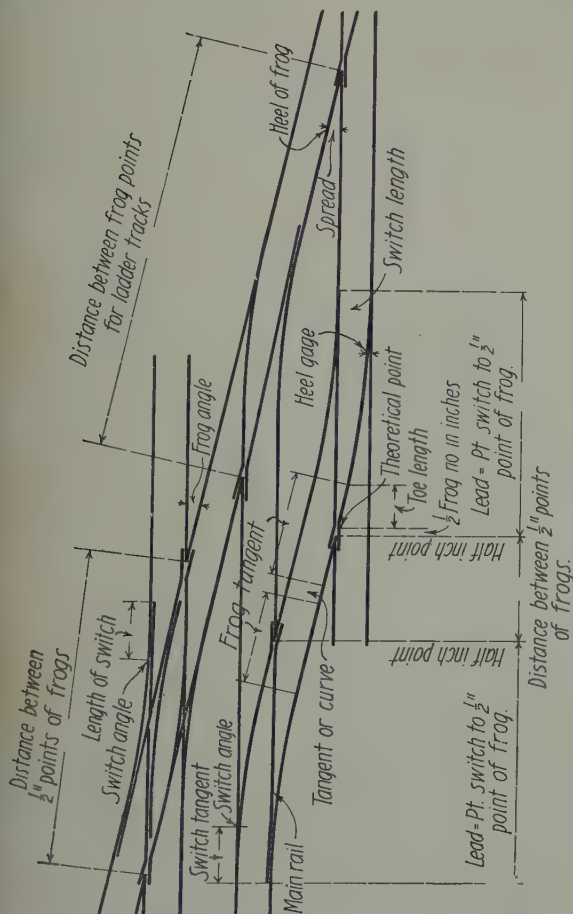


Fig. 4. Diagram Showing Different Parts of Switch Connections.

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rious problems of switch work, but through the discovery of certain exact arithmetical relations among the various functions of crossovers and ladders, and by devising empirical rules for the dimensions that do not require fine exactness, the field becomes open to all intelligent track men. The data herein assembled is offered therefore as a guide to all railroad builders and maintainers.

It is presumed that the terms commonly employed for the various functions of switch connections are entirely familiar, but in order that there may be no misunderstanding of them, their nomenclature is fully defined and their interpretation, as used, clearly indicated in the diagrams. It must be understood that the detailed design of switch and frog members, which varies somewhat with different roads, materially affects certain functions, and that it is therefore impossible to formulate rules which will apply absolutely to all cases. The empirical rules stated are for average practice, but it will be found that for even the extremes of design a relation obtains which only requires that proper constants be selected. The lead and degree of curve are the dimensions most affected by the choice of switch length and by design of the frog, but experience has shown that a slight variation in the length of the lead causes no defect in the finished work, and the degree of curve is only of incidental concern.

Theoretical leads are never directly employed in railroad switch work. The nearest approach to such

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use is in the very sharp turnouts below No. 4, wherein it is the practice to curve the turnout rail of the frog, and as the straight switch point rail still is used, the problem remains one of practical design. A rigid construction of Section 2 of the Safety Appliance Act virtually requires discontinuance of frogs below No. 5 in new work, and interest in them is only one of present maintenance and judicious elimination as opportunity arises. The problem of lining the turnout curve at the heel of the frog furnishes the one practical use for the theoretical formula for lead, and this use is only an indirect application of the geometrical principle.

The function of distance between frogs, both in crossovers and ladders, follows geometrical lines; rules for its computation should be exact and care should be taken, when applying the frogs, to use the exact dimension. This is especially true of crossovers, for even though laid on precise lines the dimension will be found after a time to vary as much as 2 in. through the creeping of the rails. This fact alone condemns the use of a formula that is often employed in computing published tables, which gives results that are too long for all crossovers, but particularly for the lower numbers of frogs. As most non-interlocked crossovers are trailing, the error thus introduced is increased by the running of the rails, the consequent tightening of the gage being very undesirable.

It is unquestionably a duty to follow standard dimensions whenever possible, with the single excep-

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tion that the lead may be varied somewhat, which indeed local conditions will often necessitate. The two dimensions especially which admit of no variation are the heel gage of the switch and the guard rail gage. Adherence to the former avoids fatiguing stresses in the switch rail and any deviation from the latter invites accident.

22. DEFINITIONS.

The term *switch connection* embraces in a general way turnouts, crossovers, ladder tracks and slip switches. *Derailing switches*, used without a frog, and *double crossovers*, formed by two simple crossovers in opposing directions which intersect, are two less common items. The *turnout* may be defined as the portion of track which forms the physical connection between two separate tracks; the *crossover*, as the combination of two turnouts to effect a connection between two thoroughfare tracks which are generally parallel; the *ladder track*, as the diagonal track from which one or more tracks diverge by separate turnouts; and the *slip switch*, as a diagonal track which crosses a thoroughfare track and has single or double connections with the intersected track.

The essential function of the switch connection is to enable trains to go from one track to another. Thus, the turnout is frequently of use to allow one train to turn aside in order to let a superior train pass; the crossover, to divert trains to an adjoining track used in the same or an opposing direction; the ladder track to furnish a compact entrance to several

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tracks; and the slip switch to afford a route not only crossing but connecting with another route.

The universal method of keeping car trucks upon the track is by means of flanges on the wheels. These impinge upon the inside lines of the rails, which are thus known as the gage lines, and the distance between the gage lines is the gage of the track. For deflecting the wheels from the track being traveled, a device is employed which is called the *switch*, and for continuing the wheels along the preferred track when the rail of an intersecting track is met, a special contrivance is used which is called the *frog*. For the benefit of the student who has not had the opportunity to gain a practical knowledge of the various members composing the switch connection, these will be described in some detail.

The *switch* consists essentially of two *point rails*, one or more *rods* to hold the points the correct distance apart and to keep them from rising, *riser* or *switch plates* to support the point rails and maintain the stock rails in position, *rail braces* to prevent the rails pushing out or turning over and a *switch stand* for throwing the switch when this is not done by a power contrivance. The tapered end is called the *point of switch* and it is usually $\frac{1}{8}$ in. thick. The opposite end is called the *heel of switch*. Each one of the point rails is known as a *switch point*. When facing the point of switch, the point on the right side is the *right hand point* and the point on the left side is the *left hand point*. When the center frogs of a crossing are replaced by point rails which move

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for the two routes, as in slip switches, these points are known as *movable points*.

The *frog* is the device used to pass the wheels running upon one rail of the track across a rail of another track. The channel in which the flanges run is called the *flangeway*. The *point of frog*, generally called the $\frac{1}{2}$ in. point, because it is $\frac{1}{2}$ in. wide, is always understood to be the actual point, and not the theoretical point which is the intersection of the gage lines. The *toc of frog* is the end nearest the switch and the *heel of frog* the end farthest away.

The simplest type of frog is the *stiff* or *rigid* frog, in which all the parts are held firmly in position. A frog having one rail which moves outward to let the flanges pass, is known as a *spring rail frog*. If it moves to the right when facing the point it is a *right hand frog*, and if to the left it is a *left hand frog*. If it has two rails which move, both to the right and left hand, it is a *sliding frog*.

Frogs are designated by their number, (which is the ratio of a bisecting line to the spread); by the weight of the rail of which they are made, and sometimes also by the different section of rail employed; and by the design, whether stiff, right or left-hand, or sliding.

The *guard rail* is an adjunct of the switch connection, which is mainly used to keep the wheels from striking or going to the wrong side of the point of the frog, but is also occasionally used in advance of switches to prevent the thin point being struck by the wheels. The stability of this member depends upon

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its being properly secured by *clamps* and *tie plate fasteners*, or by some other mode of reënforcement.

The various geometrical features of the switch connection are plainly indicated in the diagram. The lines represent the gage lines of the rails in all cases.

23. THEORETICAL AND PRACTICAL CONSIDERATIONS IN DESIGN.

Relation Between Switch Angle and Frog Angle.

—The design of switch connections embraces the determination of two distinct questions: First, the number of frog best adapted to the space available and the service required; and, Second, the length of switch most suitable for use with the selected number of frog. The former is largely an operating question; the latter can only be decided by a close analytical study of the mathematical functions. A purely theoretical consideration of the question indicates that the ideal relation exists when the switch angle is no greater than one-fourth the frog angle; but experience has shown that quite satisfactory results are obtained when this ratio is as low as 1 to $3\frac{1}{2}$. It is readily seen that any increase in the length of switch employed with a particular frog tends to increase the degree of curve of the turnout, and it is this fact mainly which restricts the choice of switch length.

Ordinary Combination of Switch and Frog.—A strict observance of the ideal relation would necessitate the employment of a larger number of standard lengths of switch than is actually required for practical results, and would add greatly to the interest

SIMPLIFIED CURVE AND SWITCH WORK

expense for emergency stock. It has been found that three or four chosen lengths answer all requirements. These are somewhat different for different roads. When no higher number of frog than No. 16 is employed the choice would be as follows: 10 ft. switch for No. 4, 5 or 6; 15 ft. for No. 6, 7, 8 or 9; 24 ft. for No. 10, 11, 12, 14, 15 or 16. If frogs as high as No. 20 were employed the choice would then be as follows: 10 ft. for No. 4, 5 or 6; 18 ft. for No. 6, 7, 8, 9, 10, 11, or 12; and 30 ft. for No. 12, 14, 15, 16, 18 or 20. It will be noted that in each case the switch length is twice the middle number of the series. When the extent and importance of the traffic warrants the use of a fourth length of switch, the first series would obtain with the addition of the 30 ft. length for use with the No. 18, 20 and 24 frogs. The preferable combinations are discussed farther on.

Difference of Length, Lead and Turnout Rails.—In the table of the principal functions for various combinations, the lead has been modified within practical limits from the strictly theoretical dimension with a view to the use of commercial lengths in the main rail, or where this is not practicable, of such lengths cut in two in the proportions necessary to make the difference between the straight lead rail and the curved turnout rail. This difference follows a regular ratio, and is obtained in every case by dividing 12 in. by the number of the connection, which it should be noted is not always that of the frog employed, but is the one which most nearly corresponds with the resultant curvature.

TABLE OF TURNOUT DIMENSIONS.

No.	Frog angle	Switch	Switch angle	Lead	Lead rail	Turnout arc	Radius	Degree	Middle ordinate
4	14° 15'	10'	2° 41'	37' 00"	20' 00"	20' 3"	98'	58° 28'	6"
5	11° 25'	10'	2° 41'	42' 00"	25' 00"	25' 2½"	162'	35° 22'	6"
6	9° 32'	10'	2° 41'	47' 00"	30' 00"	30' 2"	250'	22° 55'	5½"
7	9° 32'	15'	1° 47'	54' 00"	32' 00"	32' 2"	237'	24° 00'	6¼"
8	8° 10'	15'	1° 47'	59' 5¼"	37' 5¼"	37' 6¾"	337'	17° 00'	6¼"
9	7° 09'	15'	1° 47'	66' 11¾"	44' 11¼"	45' 0¾"	480'	11° 54'	6¼"
6	6° 22'	15'	1° 47'	72' 00"	50' 00"	50' 1¼"	626'	9° 09'	6¼"
7	9° 32'	18'	1° 30'	57' 00"	32' 00"	32' 2"	227'	25° 14'	6¾"
8	8° 10'	18'	1° 30'	63' 8½"	38' 8½"	38' 10"	332'	17° 16'	6¾"
9	7° 09'	18'	1° 30'	69' 11¼"	44' 11¼"	45' 0¾"	455'	12° 36'	6½"
10	6° 22'	18'	1° 30'	75' 00"	50' 00"	50' 1½"	588'	9° 45'	6¼"
11	5° 44'	18'	1° 30'	80' 00"	55' 00"	55' 1¼"	744'	7° 42'	6"
12	5° 12'	18'	1° 30'	85' 00"	60' 00"	60' 1"	928'	6° 10'	6"
10	5° 44'	24'	1° 07'	91' 00"	66' 00"	66' 1"	1,158'	4° 57'	5¾"
11	5° 12'	24'	1° 07'	88' 6"	57' 6"	57' 7¼"	714'	8° 01'	6¼"
12	4° 46'	24'	1° 07'	94' 00"	63' 00"	63' 1"	900'	6° 22'	6½"
15	3° 49'	24'	1° 07'	98' 5½"	67' 5½"	67' 6½"	1,075'	5° 20'	6¼"
16	3° 35'	24'	1° 07'	119' 6"	87' 6"	87' 6¾"	1,858'	3° 05'	6"
12	3° 35'	30'	0° 54'	125' 0"	93' 0"	93' 0¾"	2,149'	2° 40"	6"
15	3° 49'	30'	0° 54'	108' 5½"	71' 5½"	71' 6½"	1,058'	5° 25'	7¼"
16	3° 35'	30'	0° 54'	128' 00"	90' 00"	90' 0¾"	1,767'	3° 15'	6¾"
20	2° 52'	30'	0° 54'	134' 00"	96' 00"	96' 0¾"	2,049'	2° 48'	6¾"
24	2° 23'	30'	0° 54'	156' 00"	118' 00"	118' 0¾"	3,490'	1° 40'	6¼"
				183' 00"	145' 00"	145' 0½"	5,600'	1° 01'	5¾"

Classification of Switch Connections for Speed.—By the uses to which they are applied connections are divided into four general classes, viz.: siding connections for low speed; main track and siding connections for moderate speed; main track connections for medium restricted speed, and main track connections for the greatest practicable restricted speed.

The general division embracing siding connections consists of those over which road power cannot operate, and they are therefore less than No. 6. Because of the menace they introduce such frogs should be rigidly excluded from main tracks carrying passenger traffic. The typical frog of this class is the No. 5, which average practice fixes as the lowest number that will satisfy the requirements of the Safety Appliance Law. It requires no demonstration to show that the proper length of switch to be used with this number of frog is 10 ft. In fact, it is generally recognized that this length of switch is the minimum that may be employed with any connection.

Length of Switch With Frogs No. 6 to 9.—The second classification includes by far the largest percentage of all frogs that are in use on American railways, embracing those between Nos. 6 and 9. Bearing in mind the general use of these numbers it is plain that the adoption of a common length of switch for all is exceedingly desirable. Since each is of frequent occurrence in main tracks, the ability to cover all by a single length of switch is of unquestionable advantage.

The determination of the proper length of switch

DESIGN OF SWITCH CONNECTIONS

for use with this group concerns particularly the No. 6. This number must sometimes be used for main track connections, through which road power, including the modern types of passenger locomotives, operates not only in drill service, but quite often in main line movement. Practice permits the employment of any length of switch between 10 ft. and 18 ft. with this number of frog; but the 10 ft. length introduces a too abrupt change in direction for comfortable operation in passenger service, and causes a very considerable shock with consequent wear upon the point in the case of drill movement. On the other hand, while the 18 ft. length supplies the requisite improvement in the detour feature, the degree of curve is increased nearly 10 per cent, and the minimum thus created becomes somewhat precarious for road movement.

A reference to the table shows that the use of a 15-ft. length does not unduly increase the degree of curvature, while the switch angle is reduced one-third. This length of switch therefore appears to be more generally desirable for the No. 6 frog than either of the other lengths. It will also be seen that in the case of the No. 7 a curvature nearly equal to that with the 18-ft. switch results, and that the curvature of the No. 8 and No. 9 with the 15-ft. switch is materially less than that with the 18-ft. switch. The middle ordinate of the chord of the turnout arc is uniformly $6\frac{1}{4}$ in., which practically may be used as 6 in. with $4\frac{1}{2}$ in. at the quarters. Thus exact line may be obtained readily, which is an essential feature in switch

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construction. This length is therefore recommended as one of the standard lengths in preference to 18 ft.

Length of Switch With Frogs No. 10 to 16.—The one objection to the 15-ft. switch is that this length is not desirable with the No. 10 frog, which is in very common use on many roads. This turnout, however, more properly belongs with the class of main line turnouts through which a medium restricted speed is not only safe but comfortable, and a longer switch even than 18 ft. is desirable. It will be observed upon reference to the table that the use of a 24-ft. switch with a No. 10 frog only slightly increases the curvature above that which obtains with the 18-ft. switch, while the detour feature is again one-third improved. This also applies to the No. 11 and No. 12 frogs, which are often employed in preference to the No. 10 when space for the No. 15 is lacking. The 24-ft. length is quite desirable for the No. 15 and No. 16 frogs, and in all of these the middle ordinate is seen to be very close to 6 in.

Length of Switch With Frogs No. 18 to 24.—There still remains the fourth class wherein detour must be made at the greatest speed practicable, both as a means of maintaining headway and of avoiding loss of time while passing through the connection. The former is the more important consideration, as headway once lost usually requires a dozen miles to regain, and if adverse grade is present it may require a much greater distance. It will be conceded that a conservative limit for the unbalanced elevation of a curve is $1\frac{1}{2}$ in. This fact considered alone would

DESIGN OF SWITCH CONNECTIONS

permit the operation of Nos. 18, 20 and 24 connections, whether of turnouts or crossovers, at a speed of from 35 to 45 miles per hour. But it is neither comfortable nor entirely safe to detour through the angle made by a 30-ft. switch at a speed faster than 30 miles per hour, unless the alinement through the switch is adjusted to furnish equal advantage to the main track and the turnout routes, which would, of course, require that the speed through both routes

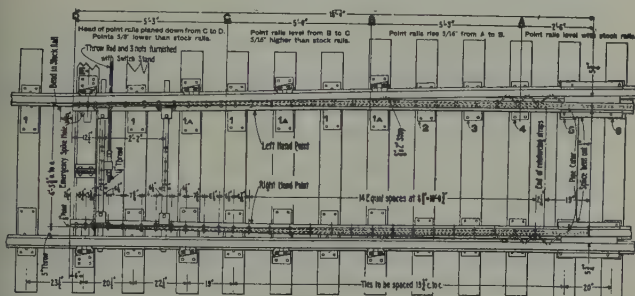


Fig. 5. P. R. R. Standard 18-Ft. Point Switch.

should be restricted alike; when a speed of 35, 40 and 45 miles per hour, respectively, would be entirely proper.

The 18-Foot Switch as a Compromise Length.—It is recognized that the 18-ft. switch is extensively used and by many of our best roads, and that it covers a wide range of numbers, viz.: between No. 6 and No. 12. It has been shown, however, that neither the 10-ft. nor the 18-ft. switch is desirable with the No. 6 frog, and, similarly, neither the 18-ft. nor the 30-ft.

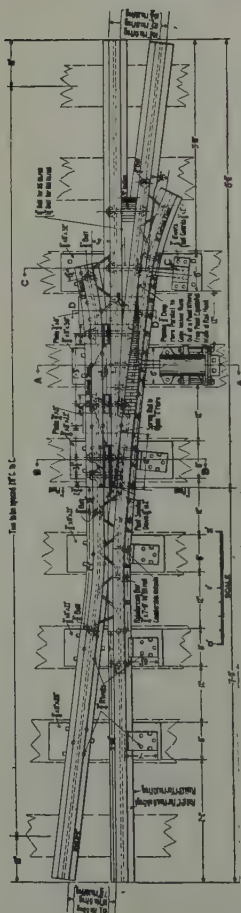


Fig. 6. P. R. R. Standard Spring Rail Frog.

length is adapted to the No. 12 frog. While the 18-ft. length is quite satisfactory with the No. 10 frog as regards curvature, it is not easy enough in the detour feature to fully meet the needs of this number in main line movement. The fact that by its use the number of working lengths may be kept at three, with a saving in stock account, has heretofore justified its use; but the increase in the size of both passenger and freight locomotives warrants the revision of standards to meet the new conditions, even though the fourth length be introduced.

Selection of Frogs for New Tracks.—The choice of stock numbers of frogs will probably always be a matter of individual preference, but a study of some of the practical considerations

in such a selection will be of interest. The No. 5 frog will be used where only drill power operates. If the drilling must be done by road power the No. 6 should

DESIGN OF SWITCH CONNECTIONS

be the minimum permissible. This number is almost invariably chosen for wye tracks, not alone because of the considerably less room required, but also because the shorter length can be traversed in less time, an important item at terminal points. It is desirable on account of the natural shifting of the track beyond the connection that the general radius be no less than 300 ft. in any case.

The No. 8 frog is the most frequently used of the group of smaller numbers. It is a common selection for main track connections with station sidings, with private industry tracks, with set-off sidings for crippled cars, and especially for yard ladders. The feature that renders it desirable for this last purpose is the fact that it is the lowest number that can be used at 15 miles per hour, and thus the greatest conservation of room will obtain without sacrifice of celerity in operation.

Nos. 10, 11 and 12 frogs are preferred for main track crossovers where only a moderate speed is required, not alone because they are safer if greater speed than the established limit should be used, but because they encroach less upon the clearance with the traffic running upon adjoining tracks, an important consideration with 12-ft. track centers. The Nos. 15 and 16 frogs are very useful where space is limited and it is desirable to make movements with speed, or where a fair degree of headway must be maintained. The Nos. 18, 20 and higher frogs are preferable where ample space is available and the highest speed practicable must be used.

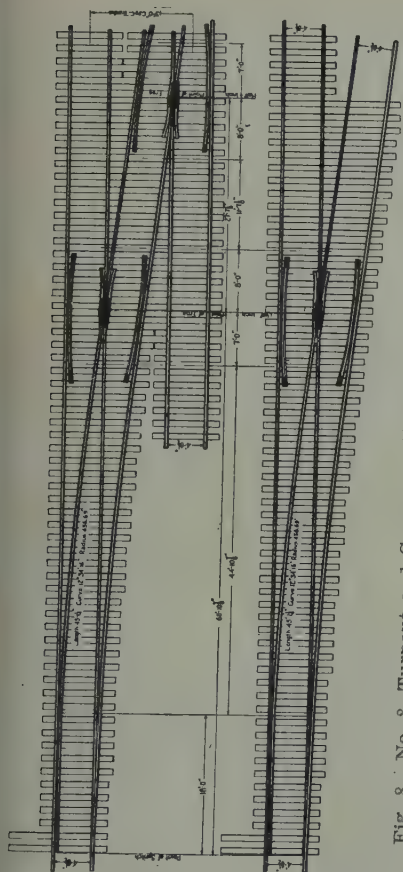


Fig. 8. No. 8. Turnout and Crossover, 13 Ft., 0 In. Center to Center of Track.

The numbers from No. 15 upward are not infrequently very useful to render the curvature favorable when the turnout is from the inside of a sharp curve; and, similarly, the No. 10 and No. 12 frogs supply the needed operating advantages of the higher numbers when the turnout is from the outside of a curve.

Frog Numbers and Switch Lengths for Standard Use.—

The question of what numbers of frogs will best

serve the uses of a trunk line railroad can be determined readily from the foregoing discussion. They will be found to be Nos. 5, 6, 8, 11, 15 and 20. It will be noted that these numbers increase in a

regular progression, and that in a general way the degree of curve of all except the second number is just half that of the next lower number. The suggested numbers will be found to supply a regularly increasing length for crossovers, and they thus furnish the means for economical use of the space available. The No. 15 and No. 20 turnouts, which are much used in interlocking layouts, employ rails that vary 5 ft. in length and thus supply the required spacing for insulated joints without the introduction of unusual lengths.

The use of the 10-ft. switch with the No. 5, of the 15-ft. switch with the No. 6 and No. 8, of the 24-ft. switch, with the No. 11 and No. 15, and of the 30-ft. switch with the No. 20, all give a uniform middle ordinate of practically 6 in. for the chord of the turnout arc. This feature supplies the opportunity for general use of a uni-

TABLE OF TURNOUT DIMENSIONS.

Frog No.	Frog angle	Switch	Switch angle	Lead	Lead rail	Turnout arc	Radius	Degree	Middle ordinate
4	14° 15'	10'	2° 41'	37' 00"	20' 00"	20' 3"	98'	58° 28'	6"
5	11° 25'	10'	2° 41'	42' 00"	25' 00"	25' 2½"	162'	35° 22'	6"
6	9° 32'	15'	1° 47'	54' 00"	32' 00"	32' 2"	237'	24° 00'	6½"
7	8° 10'	15'	1° 47'	59' 5½"	37' 5½"	37' 6¾"	337'	17° 00'	6½"
8	7° 09'	15'	1° 47'	66' 11¼"	44' 11¼"	45' 0¾"	480'	11° 54'	6½"
9	6° 22'	15'	1° 47'	72' 00"	50' 00"	50' 1¾"	626'	9° 09'	6½"
10	5° 44'	24'	1° 07'	88' 6"	57' 6"	57' 7¾"	714'	8° 01'	6½"
11	5° 12'	24'	1° 07'	94' 00"	63' 00"	63' 1"	900'	6° 22'	6½"
12	4° 46'	24'	1° 07'	98' 5½"	67' 5½"	67' 6½"	1,075'	5° 20'	6½"
14	4° 06'	24'	1° 07'	111' 11½"	80' 11½"	81' 0½"	1,560'	3° 40'	6½"
15	3° 49'	24'	1° 07'	119' 6"	87' 6"	87' 6¾"	1,858'	3° 05'	6"
16	3° 35'	30'	1° 07'	125' 0"	93' 0"	93' 0¾"	2,049'	2° 40'	6"
18	3° 11'	30'	0° 54'	145' 11¾"	107' 11¾"	108' 0¾"	2,720'	2° 07'	6½"
20	2° 52'	30'	0° 54'	156' 00"	118' 00"	118' 0½"	3,490'	1° 40'	6½"
24	2° 23'	30'	0° 54'	185' 00"	145' 00"	145' 0½"	5,600'	1° 01'	5¾"

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form rule in lining the turnout curve, which is a very considerable advantage. It is well known that even on main line divisions poor line through the turnout arc is quite common, and this defect may be traced to the practice of lining the curve by eye, or what is almost equally unsatisfactory, by a system of offset measurements. In the rush of lining such connections the simpler the process the better the result obtained.

Speed Twice the Frog Number.—The approximate speed in miles per hour that may be used through connections, assuming the curvature to be at least 50 per cent greater than will just pass the power in question, is about double the frog number, and it thus will be seen that the numbers recommended furnish a regular progression in this respect also.

CHAPTER IX.

RULES FOR COMPUTING SWITCH DIMENSIONS.

24. THE LEAD.

The lead is the principle dimension of the turnout. It is the distance measured along the main rail between the actual point of switch and the actual, or, $\frac{1}{2}$ -in., point of frog. *The proper lead is that one which makes the tangents through the switch and the frog meet at a point midway between these members.* This not only provides regular curvature, but the lowest degree of curvature that is possible for the connection. The function of the lead is therefore dependent not only upon the number of the frog, but upon the length of switch used and also upon the toe length of frog. A turnout is almost equally satisfactory with any one of several different lengths of switch, provided in each case the proper lead is used. Thus, a No. 6 turnout may have any length of switch between 10 ft. and 18 ft., and a No. 12 any length between 18 ft. and 30 ft. It is generally considered, however, that the selection which renders the ratio of switch angle to frog angle about as 1 to 4 is most satisfactory. This in effect signifies that with $5\frac{3}{4}$ in. heel gage the length of switch should be about twice the frog number.

The frog length in the lead being generally the same for all turnouts in the same class, the variable part of the lead will be the length of rail between

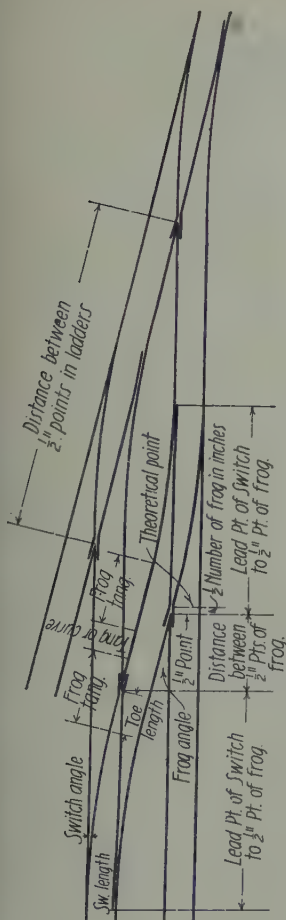


Fig. 9. Diagram of Principal Dimensions for Turnouts and Crossovers.

the frog and switch. This may be expressed in multiples of the frog number, with sufficient accuracy for general use.

The empirical rule given below will be found quite in accord with accepted standards when a toe length between 6 ft. and 7 ft. obtains. If a shorter toe length is the rule, the constants may readily be changed to furnish exact agreement with the leads that are proper for such reduced toe length. In fact, when this means of expressing the function of the lead is adopted as a memory aid, which is its main purpose, the constants should be first adapted to the practice that obtains on

the particular road.

Length of Track Rails in Lead.—*The length of rail in the lead is 5 times the number of the frog for*

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a 10 ft. switch, $5\frac{1}{2}$ times for a 15 ft. or an 18 ft. switch, $5\frac{3}{4}$ times for a 24 ft. switch and 6 times for a 30 ft. switch.

It is only necessary to add the switch length and the toe length of frog to the figures thus computed to obtain the practical lead. This rule is not only useful as a memory aid, but it furnishes the means of obtaining readily the proper lead in the event that a frog of special number is employed, for which no standard lead is announced.

The permissible variation from regular lengths of lead is 2 ft. for a No. 6 connection and 8 ft. for a No. 20 connection and a due proportion for intermediate lengths. Provided these limits are not passed, it is entirely proper to modify the length of lead so that regular lengths of rail may be employed. In the table which accompanies the discussion of the essential elements of design it is shown how the lead may be accommodated to the rail length.

Excepting only the case where a frog is the crotch of two equal curves turning in opposite directions, there is a regular ratio of difference between the length of the lead rail and of the turnout arc, and this difference will be obtained by dividing 12 inches by the frog number. When the turnout is from a curve the frog number to be used is the one that most nearly corresponds with the resultant curvature of the turnout.

25. THE DEGREE OF CURVE.

Margin of Accuracy.—For the purpose of the supervisor and the foreman the degree of curve may

be defined as the number of inches the rail deflects from the middle of a string 61 ft. 8 in. in length held to contact at its two ends, fractions of the inch being multiplied by 60 to supply the minutes of arc. The degree of curve of a turnout does not figure in any way in its installation and is only of consequence in determining the class of power which may be permitted to operate through it, or the limit of speed to be prescribed, or the templates to be used in plotting a switch layout. The motive power experts do not assume to fix the limit of practical operation nearer than 50 per cent above the curvature that may be just passed, and it is recognized that enginemen cannot regulate speed closer than 10 per cent, and for plotting the last margin is also ample. An empirical rule, therefore, which enables the investigator to approximate the curvature within 10 per cent will satisfy all practical requirements.

Effect of Frog, and Switch Rail.—It is, of course, understood that the degree of curve of a properly designed turnout depends both upon the length of switch rail and the toe length of frog. The shorter these two members are the more nearly does the curve approach the theoretical degree, which is, of course, the minimum. The heel gage admits of little variation from $5\frac{3}{4}$ in., which provides about 3-in. flangeway, and a reduction in the length of the switch rail only increases the abruptness with which the turnout deflects from the main track. It is recognized that a 10 ft. length of switch point is the mini-

num for the best service. Similarly, the toe length of frog for modern hard-center construction can hardly be less than 5 ft. for any frog, and must be for No. 8 and No. 10 frogs no less than 5 ft. 6 in. and 6 ft., respectively, to avoid the use of filler blocks for the joints. It may, therefore, be considered that the combinations shown in the table represent good practice, and it is upon those dimensions that the approximate ratios of curvature as given below are laid.

It will be found, however, that the ratios of curvature for different frog numbers will hold with no more than 10 per cent error for the specified designs in use on any particular road, and the value for the basic turnout being determined the values for the others will follow the same ratios in all cases. Thus, the road that prefers short switch points and frogs might have a value as low as 19 deg. 30 min. for the curve of a No. 6 turnout, which would require the use of 8 ft. point rails and 4 ft. 6 in. toe length of frog. If turnouts of other numbers followed the same general type, the ratios would produce the degrees of curvature for all cases.

Radius and Degree of Turnout Curve Leading from Tangent.—*The radius of a No. 6 connection from tangent track is 250 ft. The radius of a No. 8 is twice this, of a No. 10 three times, of a No. 11 four times, of a No. 13 five times, of a No. 14 six times, of a No. 15 seven times, of a No. 16 eight times and of a No. 20 thirteen times. The degree of curve of a No. 6 is 23 deg. and the degree of curve*

of the other turnouts mentioned varies inversely in the above ratios.

Degree of Turnout Curve Leading From Curved Track.—To determine the degree of curve of a turnout from curved track, it is only necessary to add the degree of the main track curve to the normal degree of the turnout when the connection is from the inside and to subtract it from the normal degree when the connection is from the outside. In the latter case, if the subtrahend should be the greater, the result would be a minus quantity, and this would indicate that the connection, instead of turning away from the main track, curved in the same direction. If in any case the radius were desired, it might be obtained with a sufficient accuracy by dividing 5730 by the resulting degree.

26. THE FROG NUMBER.

The number of a frog is the ratio of the length of a bisecting line to the spread at the end of such line. This bisecting line must be measured from the theoretical point of frog, or a proper allowance made for the distance between the theoretical and practical points. It is not correct to use the ratio of a length along the sides of the frog point to the spread, although for frogs of less angle than the No. 6 no sensible error will result therefrom. If the spread in such a case is measured as the equal segments of a broken line, with each half at right angles with one side of the frog, the process will be rendered exact. This proposition furnishes a convenient and accurate

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means of determining the frog number. The length of frog is always measured along the running rails. This length divided by the sum of the spread at the

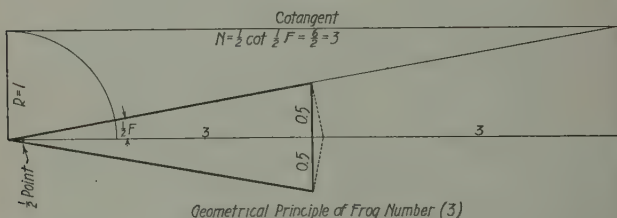


Fig. 10. Diagram Showing Frog Number and How Obtained.

two ends, measured between the gage lines and in the manner indicated by the broken lines in Fig. 10, will give the exact number of the frog.

27. THE FROG ANGLE AND SWITCH ANGLE.

It is not infrequently necessary to know the exact frog and switch angle, especially for the purpose of computing the precise degree of curve of the turnout. The degree of curve for turnouts from straight track is found by subtracting the switch angle from the frog angle and dividing the remainder by the length of curve between the switch and the frog.

One of the necessary dimensions to be remembered in all railroad engineering is the length of radius of a 1 deg. curve, which, as is well known, is 5,730 ft. It happens that this dimension expressed in chain lengths, or what is equivalent, divided by 100, supplies the constant necessary to obtain the

COMPUTING SWITCH DIMENSIONS

frog angle. The frog angle in degrees and decimals of a degree is found by dividing the constant 57.3 by the frog number. The results by this rule are practically exact for frogs above No. 6, and nearly so for frogs of No. 6 and lower.

If the difference between the thickness of the switch point, which is usually $\frac{1}{8}$ in., and the heel gage were just 6 in., the same constant divided by twice the length of switch would equal the switch angle. It is, however, only necessary to compute a new constant which will be to 57.30 as the actual difference is to 6. This difference is $5\frac{5}{8}$ with a $5\frac{3}{4}$ in. heel gage and the constant is found to be 53.70. This figure divided by twice the length of switch will give the switch angle within a few seconds.

28. DISTANCE BETWEEN $\frac{1}{2}$ IN. FROG POINTS IN CROSSOVERS.

An exact rule for calculating the distance measured along the main track between the actual or $\frac{1}{2}$ in. points in a crossover, is as follows:

Subtract twice the gage from the track centers, multiply by the number of the frog, subtract inches equal to the number of the frog and further, subtract the quotient obtained in dividing the track centers by four times the frog number.

Thus this dimension for No. 6 crossover with 13 ft. centers is obtained as follows: 13 ft. 0 in.—2 (4 ft. $8\frac{1}{2}$ in.) = 3 ft. 7 in. x 6 = 21 ft. 6 in.—6 in.—13 ft. 0 in.
 $\frac{13 \text{ ft. } 0 \text{ in.}}{4 \times 6} = 20 \text{ ft. } 5\frac{1}{2} \text{ in.};$ and for No. 8 cross-

DISTANCES BETWEEN LADDER FROG POINTS, MEASURED ALONG LADDER.

No. of Frog	12			12½			13			13½			14			14½			15		
	ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.	
6	72	6		75	6¼		78	6½		81	6¾		84	7		87	7¼		90	7½	
7	84	5		87	11¾		91	5¾		94	11¾		98	6		102	0¼		105	6½	
8	96	4½		100	4¾		104	5		108	5		112	5¼		116	5½		120	5¾	
9	108	4		112	10½		117	4¼		121	10½		126	4¾		130	10¾		135	5	
10	120	3½		125	3¾		130	4		135	4½		140	4¼		145	4¾		150	4¾	
11	132	3¼		137	9¾		143	3¾		148	9¾		154	3¾		159	10		165	4¾	
12	144	3		150	3		156	3¼		162	3¾		168	3½		174	3½		180	3¾	
14	168	2½		175	2¾		182	2¾		189	2¾		196	3		203	3½		210	3¼	

DISTANCES ALONG MAIN TRACK BETWEEN ½ INCH POINTS OF FROGS IN CROSS-OVERS.

No. of Frog	12			12½			13			13½			14			14½			15		
	ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.		ft.	in.	
6	14	6		17	5¾		20	5¼		23	5¼		26	5		29	4¾		32	4½	
7	17	0¾		20	6¾		24	0¾		27	6¼		31	0		34	5¾		37	11½	
8	19	7½		23	7¼		27	7½		31	7		35	6¾		39	6¾		43	6¾	
9	22	2		26	7¾		31	1¾		35	7½		40	1¾		44	7½		49	1	
10	24	8¾		29	8¼		34	8¾		39	8		44	7¾		49	7¾		54	7½	
11	27	2¾		32	8¾		38	2½		43	8¾		49	2½		54	8		60	1¾	
12	29	9¾		35	8¾		41	8¾		47	8¾		53	8½		59	8¾		65	8¼	
14	34	9½		41	9¼		48	9¼		55	9¾		62	9		69	8¾		76	8¾	
15	37	3¾		44	9½		52	3¾		59	9¾		67	3¼		74	9½		82	3½	
16	39	9¾		47	9¾		55	9¾		63	9½		71	9¾		79	9¼		87	9½	
18	44	10		53	9¾		62	9¾		71	9¾		80	9¾		89	9¾		98	9½	
20	49	10¼		59	10¾		69	10		79	10		89	9¾		99	9¾		109	9¾	

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over with 12 ft. 2 in. centers as follows: 12 ft. 2 in.
— 2 (4 ft. 8½ in.) = 2 ft. 9 in. x 8 = 22 ft. 0 in.

— 8 in. — $\frac{12 \text{ ft. } 2 \text{ in.}}{4 \times 8} = 20 \text{ ft. } 11\frac{1}{2} \text{ in.}$

This rule is especially useful where a crossover is to be installed between tracks that have a different intertrack distance than the standard, or where frogs of different numbers are to be combined in the same crossover. In the latter case the multiplier is the mean of the two frog numbers and the subtrahend and item in the divisor the same mean figure.

The rule as generally given heretofore makes no mention of the further correction, and the error through this omission may readily be figured as 6½ inches for a No. 6 crossover with 13 ft. 0 in. centers of tracks.

It is mistakenly thought by some that a different distance between actual or ½ in. points should be used when the crossover is on a curve; but all linear dimensions for such a case remain the same. The effect is merely to introduce between the frogs a curve similar to the main track curve, and turning in the same direction, in place of the usual tangent track.

29. DISTANCE BETWEEN FROGS IN LADDERS.

The problem of obtaining the distance between frog points for ladder tracks to be measured along the ladder involves tedious computation by tables that the following simple rule which is exact will avoid:

Multiply the track centers by the number of the frog and add the quotient obtained in dividing the track centers by four times the frog number.

Thus this dimension for No. 10 frog and 15 ft. 0 in. track centers is obtained as follows: $15 \text{ ft.} \times 10 + \frac{15 \text{ ft. } 0 \text{ in.}}{4 \times 10} = 150 \text{ ft. } 4\frac{1}{2} \text{ in.}$; and for No. 8 frog and 13 ft. 0 in. centers as follows: $13 \text{ ft. } 0 \text{ in.} \times 8 + \frac{13 \text{ ft. } 0 \text{ in.}}{4 \times 8} = 104 \text{ ft. } 5 \text{ in.}$

Curved Ladders.—The above method is correct whether the ladder is straight or curved. A curved ladder is always proper when the main tracks are on a curve, and the degree and direction of curvature of the ladder will be exactly the same as those of the tracks with which the ladder connects. A very common error is to endeavor to introduce a straight ladder for a system of curved tracks. If the degree of curve is small the result may not be bad for the first few frogs, but the error grows as tracks are added and soon requires that another number of frog be used, and may necessitate the employment of special frogs. It is certain to furnish very imperfect general results.

When designing a ladder for curved tracks, due consideration must be given the fact that the curvature, whether the turnout be from one side or the other of the main-track curve, is no greater than the difference between the normal degree for the selected number of frog and the degree of the main track curve. The advantage in recovery that obtains in the case of a simple turnout from curved track to a parallel siding does not obtain in a ladder.

Lining a Ladder.—The computed dimensions for ladders furnish a ready means of alining them and

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are equally applicable whether the ladder connects with tangent or curved track.

A convenient method of lining a new ladder track, connecting either with a tangent or curved main track, follows closely the definition of the frog number. Equal distances may be laid off along the outside rail of the main track from the theoretical point of frog, which is one-half the frog number in inches

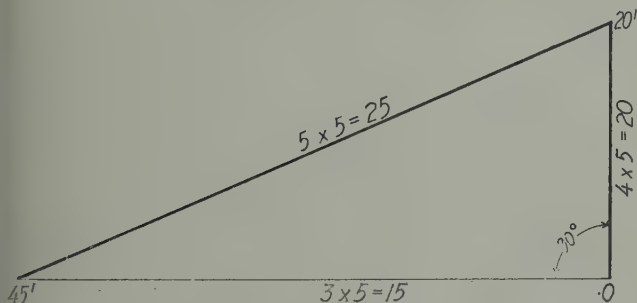


Fig. 11. Method of Laying Out a Right Angle.

ahead of the $\frac{1}{2}$ in. point, and right-angle measurements made to the near rail of the ladder. These offsets will be obtained by dividing the distances by the number of the frog. For convenience, the equal distances may be made an even multiple of the frog number, as 48 ft. for a No. 6, 8 or 12; when the first offset would be 8, 6 or 4 ft. respectively, the second one twice this, and so on.

A right angle may be accurately turned from a tangent rail by stretching a metallic tape line taut with the zero end held at the point to be turned, the 45 ft. mark held at a point 15 ft. distant, the tape

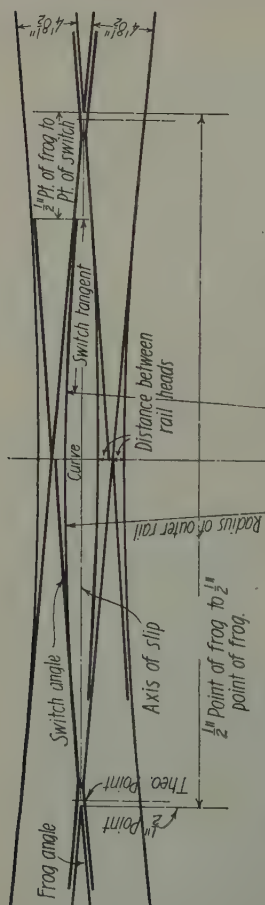


Fig. 12. Diagram of Double Slip Switch.

line being grasped at the 20 ft. mark. This furnishes a right angle triangle with the sides in the ratio of 3, 4 and 5.

30. DISTANCE BETWEEN $\frac{1}{2}$ IN. FROG POINTS IN SLIP SWITCHES.

It is not so important to remember the dimensions which apply in slip switches, as, excepting the distance between the $\frac{1}{2}$ in. points of frogs, the dimensions are largely dependent upon details of design, (such as the length of the switch and the point where the turnout curve originates), and the standard plan must necessarily be consulted. It is well, however, to know the following rule, which is practically exact, for obtaining the distance between the

$\frac{1}{2}$ in. points measured along the axis of the slip. It follows the same geometrical solution as in a plain ladder, the difference being that the correction for $\frac{1}{2}$

in. points do not negative each other, but are additive; and twice the gage replaces the track centers in the principal function and the further correction applies only to the gage distance for the ladder track. The distance between $\frac{1}{2}$ in. points of frog in extension of the ladder to adjoining tracks should be obtained by the rule for simple crossovers. To find the distance between actual or $\frac{1}{2}$ in. points in slip switches:

Multiply twice the gage by the frog number and add inches equal to the number of the frog and further, add the quotient obtained in dividing the gage by four times the frog number.

Thus, this dimension for a No. 6 slip switch, with 4 ft. 9 in. gage is obtained as follows: 2 (4 ft. 9 in.)

$$\times 6 + 6 \text{ in.} + \frac{4 \text{ ft. } 9 \text{ in.}}{4 \times 6} = 57 \text{ ft. } 8\frac{3}{8} \text{ in.}; \text{ and for}$$

a No. 15 slip switch, with 4 ft. $8\frac{1}{2}$ in gage, as follows: 2 (4 ft. $8\frac{1}{2}$ in.) $\times 15 + 15 \text{ in.} + \frac{4 \text{ ft. } 8\frac{1}{2} \text{ in.}}{4 \times 15}$

$$= 142 \text{ ft. } 7 \text{ in.}$$

CHAPTER X.

RULES FOR VARIOUS FUNCTIONS OF TURNOUTS.

31. LINING THE TURNOUT CURVE.

The curve of the turnout should always be established by the use of the string. It has been found that for all turnouts from straight track no matter what the frog number, *if the adopted practical leads are used*, the middle ordinate of a string drawn between the heel of switch and toe of frog is 6 in., and the ordinates at the quarter points of the string are each $4\frac{1}{2}$ in. For turnouts from the inside of a curve the middle ordinate is 6 in., plus the ordinate of the main track curve obtained with the same length of string as used for the turnout; and for turnouts from the outside of a curve the middle ordinate is 6 in. minus the ordinate of the main track curve, the quarter ordinates in both cases being computed as three-fourths the resulting middle ordinate.

If the turnout is a very long one it is sometimes useful, after fixing the position of the rail at the middle and quarters, to draw the string to a contact at the middle point, when by the principle that ordinates vary approximately as the square of the chords, the new ordinates at the original quarter points will be found to be one-fourth the original middle ordinate; and additional points may be established at the quarters in each half by ordinates which are computed as three-fourths of the middle ordinate from the half string.

Lining Track Behind Frog.—The matter of lining the curve at the heel of the frog is almost invariably left to the eye of the foreman with the result that this part of the turnout is usually the most irregular and the one incidentally where the greatest number of derailments occurs, especially in the sharper turnouts. When the curve at the heel is continuous with the curve of the lead, the line is sometimes established with the instrument at the time the layout is made; or else the curve may be exactly alined by a proper use of the method of ordinates. But for turnouts which reverse into a parallel track a rule can be stated that will apply to all cases, and will furnish a direct method of establishing at once both a regular curve and the one of largest radius possible for the connection.

There is a mistaken impression, and it is even stated as a rule for guidance in a book on switch work which has considerable use, that in such lining the frog tangent should be extended to the same length as that obtaining in a crossover. This is not correct because the shorter the tangent of the curve, the greater will be the degree of curve, and if no limiting features are present the curve should be made as long as practicable, and it may even be desirable to establish the P. C. at the heel of the frog. This is especially important where the turnout is from the outside of the curve. In such a case it may be essential to use this advantage with the alternative circumstance that the turnout may enter a different class for operation. Thus, if a No. 6 connection is limiting for road power, such a connection from the outside of a 5 deg. curve, with the point of curve at the

heel of frog, would just remain within the limit. Alined in the manner of a crossover, the curvature would become 28 deg., or 207 ft. radius, and the connection be open only to switch engines.

The suggested practice adds to the operating efficiency of the turnout without appreciable sacrifice of standing room on the siding and is a maintenance advantage as well, because that part of the turnout, not being secured as is the lead portion, is subject to traffic shifting and requires a greater initial radius to remain with even moderate supervision within the required degree of curvature. This proposition being accepted, the rule for lining when the P. C. is established at the heel of the frog may be stated, which follows a similar geometrical solution to that for theoretical lead except that the item of gage is replaced by the off-set from the heel of the frog on the turnout rail to the line of the near rail of the parallel track. The computation, when any other point on the frog tangent is used, follows an exactly similar solution, but correction of the middle ordinate must be made in the proportion of the squares of the chords.

Rule for Lining the Curve Back of Frog.—From the distance between gage lines of the parallel tracks subtract the spread at the heel of the frog and multiply by twice the number of the frog, which gives the distance to be measured along the main track from the heel of frog to the point at right angles with the end of the curve, whether the turnout be from straight or curved track. For turnouts from straight track, measure from the middle of a string drawn between this point and the heel of the frog an

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ordinate of 20 in., and from the quarter points an ordinate of 15 in., which will give three essential points in the curve. For turnouts from curved track the middle ordinate must be increased by the amount of the ordinate of the main track curve, obtained with the same length of string, when the turnout is from the outside, and similarly decreased when the turnout is from the inside of the main track curve; the quarter ordinates will be three-fourths the resulting middle ordinates in all cases.

Thus, for the No. 10 connection with a siding on the outside of a 4 deg. curve, on 12 ft. 2 in. centers with the main track, the distance to be measured from the heel of the frog to the end of the curve would be obtained as follows: 7 ft. $5\frac{1}{2}$ in. — 10 in. = 6 ft. $7\frac{1}{2}$ in. $\times 20 = 132$ ft. 6 in. The middle ordinate of a 4 deg. curve being 18 in. the ordinate to be measured at the middle in lining the curve at the heel is 20 in. + 18 in., or 38 in., and at the quarters, three-fourth of 38 in., or $28\frac{1}{2}$ in.

When the turnout is above No. 10 the use of the string becomes inconvenient and a method by offset measurements is generally preferable. The calculation for total length along the main track is the same. This distance may be divided into three or four parts and the offset from the imaginary parallel track will be the proportion of the offset distance at the P. C. represented by the square of the fractional distance from the P. T. These may be made supplements of the distance between the main track and the parallel track and direct measurements be used to locate the turnout curve. This method applies nearly as well to the lower numbers of frog, and is correct whether

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the main track is tangent or curve or in part both. The resulting curve is not quite circular, but this is an advantage both in operation and maintenance.

For lining the turnout curve and the tangent and curve back of the frog, the maintenance standards of some roads furnish offset distances from the main rail at established intervals. These are very useful provided care is taken that the measurements are made exactly at right angles. It should be noted that these offsets are identical for all different conditions of layout whether the turnout is from tangent or curve. The principal disadvantage is that the dimension data are not always at hand, and they are too many to be remembered.

32. DESIGNING THE BILL OF SWITCH TIES.

It is very necessary that the supervisor shall be able to instruct his foreman how to make up and apply a set of switch ties, especially for new work, so that when the switch work is completed the timbers will line up on both sides accurately. The average foreman will err on the side of excess, probably with the thought that timbers can be cut off but never pieced out. This results in measurable loss, both for the timber wasted and for the labor necessary to correct the error.

The published bill of material for various turnouts and crossovers, which is practical enough for purchasing department purposes, supplies no guide either in selecting or applying the ties. Even if by clever interpolations a working bill is made up from the general bill it does not furnish any check upon its installation.

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The rule for lining the curves of turnout furnishes a practical means of calculating the lengths of the switch ties for the middle and quarter points between the heel of switch and toe of frog, and these are found to be practically the same for all turnouts. The length at the middle is 10 ft. 4 in., at the quarter nearest the switch 9 ft. 5 in., and at the quarter nearest the frog 11 ft. 5 in. The timber at the heel of the switch is always 9 ft. 0 in., but that at the toe of the frog varies according to the spread of the frog. It is 12 ft. 9 in. for No. 24, No. 20 and No. 15 frogs, 12 ft. 8 in. for a No. 10 frog, 12 ft. 5 in. for a No. 8 frog and 12 ft. 2 in. for a No. 6 frog. It is, of course, well known that the timber at the point of frog of all turnouts is 13 ft. 3 in.

Ties Between Switch and Frog of Turnouts and Crossovers.—There is thus at hand a practical check upon the bill to be designed, as well as upon the correctness of the installation. This bill may be obtained off-hand by the following simple rule, which is fairly accurate for all turnouts, either from straight or curved track:

Determine first what number of ties will be required between the heel of switch and the toe of frog and divide this number by 3. Calculate the increase at the frog by dividing 23 in. (or any other spacing center to center of ties that may be preferred) by the number of the frog. Beginning with 9 ft. 0 in. set down lengths for the first third by adding successively one-third the increase at the frog, and for the second third by adding two-thirds of the increase

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at the frog, and for the last third by adding the full increase at the frog.

BILLS OF TIMBER BETWEEN HEEL OF SWITCH AND TOE OF FROG.

(Ties 22½ Inch Centers.)

No. 5 Turnout or Crossover.

ft. in.	ft. in.	ft. in.	ft. in.
9 0	9 4	10 0	10 10
9 1	9 6	10 3	11 3
9 3	9 9	10 6	11 7

No. 6 Turnout or Crossover.

ft. in.	ft. in.	ft. in.	ft. in.
9 0	9 5	10 2	11 4
9 1	9 6	10 4	11 8
9 2	9 7	10 6	11 11
9 3	9 9	10 9	12 2
— —	9 10	11 1	— —

No. 8 Turnout or Crossover.

ft. in.	ft. in.	ft. in.	ft. in.
9 0	9 6	10 3	11 3
9 1	9 7	10 5	11 5
9 2	9 8	10 7	11 8
9 3	9 9	10 9	11 10
9 4	9 11	10 10	12 1
9 5	10 2	11 0	12 4

No. 11 Turnout or Crossover.

ft. in.	ft. in.	ft. in.	ft. in.
9 0	9 5	10 3	11 4
9 1	9 6	10 5	11 6
9 1	9 7	10 6	11 8
9 2	9 8	10 7	11 10
9 3	9 10	10 9	12 0
9 3	9 11	10 10	12 2
9 4	10 0	11 0	12 5
9 5	10 2	11 2	12 7
— —	— —	— —	12 9

No. 15 Turnout or Crossover.

ft. in.	ft. in.	ft. in.	ft. in.
9 0	9 6	10 4	11 6
9 0	9 6	10 5	11 7

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9 1	9 7	10 6	11 9
9 1	9 7	10 7	11 10
9 2	9 8	10 8	12 0
9 2	9 9	10 9	12 1
9 3	9 10	10 10	12 3
9 3	9 11	10 11	12 4
9 4	10 0	11 0	12 6
9 4	10 1	11 1	12 7
9 5	10 2	11 3	12 9
9 5	10 3	11 4	— —

No. 20 Turnout or Crossover.

ft. in.	ft. in.	ft. in.	ft. in.
9 0	9 6	10 4	11 6
9 0	9 6	10 4	11 7
9 1	9 7	10 5	11 8
9 1	9 7	10 6	11 9
9 1	9 7	10 7	11 10
9 2	9 8	10 7	11 11
9 2	9 8	10 8	12 0
9 3	9 9	10 9	12 2
9 3	9 10	10 10	12 3
9 3	9 10	10 10	12 4
9 4	9 11	10 11	12 5
9 4	10 0	11 0	12 6
9 4	10 1	11 1	12 7
9 5	10 1	11 2	12 8
9 5	10 2	11 4	12 9
9 6	10 3	11 5	— —

It will be found that the last tie in the last third approximates the length computed for the toe of the frog and that the ties at the middle and quarters are practically the same lengths as was computed for those points. To illustrate: The number of ties between the switch and frog of a No. 15 turnout is 47. The increase at the frog is $1\frac{1}{2}$ in. The respective increments are, therefore, $\frac{1}{2}$ in. for the first 16 ties, 1 in. for the second 16 ties and $1\frac{1}{2}$ in. for the last 15 ties. It will be instructive to write down the full bill and note that the 12th tie is 9 ft. 5 in., the 25th tie

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10 ft. 4 in., the 37th tie 11 ft. 6 in., and the 47th tie 12 ft. 9 in.

If the turnout leads to a parallel track, the length of the switch ties through the frog and beyond, increases to the last tie at the uniform rate calculated for the increase at the frog. If the turnout continues to curve away from the main track the timbers beyond the frog must be correspondingly lengthened.

Long Ties for Crossovers.—The rule will be used in the same manner to obtain the lengths of the short ties in a crossover. The length of the last short tie will equal the track centers and the length of the long ties will equal the track centers plus the standard cross-tie length. It is then only necessary to determine the number of long ties that attach to a particular set, which in turn will indicate the limits within which the long ties occur. For 12 ft. 7 in. centers the number of long ties in a crossover is $2\frac{1}{2}$ times the number of the frog. This ratio is $2\frac{2}{3}$ for 12 ft. 2 in. centers and $2\frac{1}{3}$ for 13 ft. 0 in. centers. As the last short tie before reaching the No. 10 frog is 12 ft. 7 in. it will readily be seen that for those centers the entire space between the toe of the two frogs will be laid with a total of 25 long ties of a uniform spacing of 23 inch centers. In a No. 15 crossover on the same track centers there would be long ties not only through the extent of the frogs but for three ties either side the frog, or a total number of such ties of 37. The ties under slip switches follow standard designs of layout and the plans should be consulted in selecting and applying the ties, as well as in the other parts of the work.

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Obtaining the Bill of Ties in Renewals.—When renewal of an existing turnout or crossover is to be made, it is a very simple procedure to measure the distance between the gage lines of the two outside rails over each tie, provided they are properly spaced, and if not, then at the points where with proper spacing ties would occur, and add to the figures thus obtained the constant 3 ft. 10 in., which will give the proper lengths of ties to be used. It is a still simpler method to hold lining sticks outside the rails where the new switch ties should be placed, and then measure the lengths for the ties from the end of one stick to the other.

33. NARROW GAGE SWITCH CONNECTIONS.

Even though a sixth of the railroad mileage of the world is of narrow gage, the introduction of matter pertaining to such gage would perhaps not be altogether appropriate here, were it not for the fact that increased attention is being directed toward the industrial field of South America, where the narrow gages, particularly meter gage, are in common use. The subject is also of direct local concern through the rather extensive employment of both the 3 ft. 0 in. and 3 ft. 6 in. gages in contractors' railways.

A broader gage than the standard, principally 5 ft. 6 in., is used quite extensively in certain sections of the world and its total mileage approximates that of narrow gage, but its use in America is not being extended and it thus has no direct interest.

As the distance between frogs in crossovers, ladders and slips is a purely geometrical function, the rules for its computation are equally applicable to all

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gages and the ratios of curvature also remain the same, but a different value attaches to the basic turnout. It is further necessary to design new constants

NARROW GAGE SWITCH CONNECTIONS.

No.	Factor	Lead Rail	Lead	Radius	Degree	Mid. Ord.
6	2.50	15' 0"	37' 0"	115'	51° 30'	3"
7	2.64	18' 6"	40' 6"	168'	34° 40'	3"
8	2.75	22' 0"	44' 0"	236'	24° 30'	3"
9	2.83	25' 6"	47' 6"	318'	18° 06'	3"
10	2.88	28' 9"	50' 9"	420'	13° 40'	3"
11	2.92	32' 0"	54' 0"	535'	10° 44'	3"
Functions for 3' 0" Gage						
6	3.2	19' 2½"	41' 2½"	155'	40° 25'	3¾"
7	3.2	22' 5"	44' 5"	214'	28° 35'	3⅝"
8	3.2	25' 7¼"	47' 7¼"	265'	21° 00'	3½"
9	3.2	28' 9½"	50' 9½"	362'	15° 54'	3⅜"
10	3.2	32' 0"	54' 0"	471'	12° 20'	3¼"
11	3.2	35' 2½"	57' 2½"	594'	9° 43'	3⅛"
Functions for Meter Gage						
6	4.3	25' 9½"	47' 9½"	192'	30° 12'	5⅛"
7	4.3	30' 1¼"	52' 1¼"	269'	21° 25'	5"
8	4.3	34' 4¾"	56' 4¾"	367'	15° 40'	4⅞"
9	4.3	38' 8½"	60' 8½"	485'	11° 50'	4⅝"
10	4.3	43' 0"	65' 0"	626'	9° 10'	4½"
11	4.3	51' 3½"	73' 3½"	860'	6° 40'	4⅜"
Functions for 3' 6" Gage						

for the length of lead rail and for the middle ordinate in lining.

Length of Switch Rail.—The choice of switch length is more important in narrow gage than in standard gage. Since the ostensible purpose in building a new railroad of narrow gage is economy in first cost, however little this feature may be realized in after operation, a variety of switch lengths is out of the question and, indeed, a single length only is permissible. This length should not alone satisfy the essential requirements of the connection, but should be such that upon change of the gage to the standard the points may continue in use.

As the 15 ft. length has been found quite suitable for employment in standard gage with the entire

FUNCTIONS OF TURNOUTS

group of frogs that are in most general use, it is proper to consider this length in its relation to narrow gage connections. A thorough study of the resultant degree of curve and of the middle ordinate for lining will show that the 15 ft. length is entirely satisfactory. A table is furnished giving the principal functions for 3 ft. 0 in., meter, and 3 ft. 6 in. gages. It will be noted that for 3 ft. 0 in. gage a middle ordinate of 3 in. is proper, for meter gage $3\frac{1}{2}$ in. and for 3 ft. 6 in. gage $4\frac{3}{4}$ in., and that these apply practically to all frogs, as was to be expected from the preceding study of standard gage functions.

Length of Lead.—The lead in narrow gage switch work admits of little deviation from the ideal lengths, and the multiplier to obtain the length of track rail will therefore not be constant for the different numbers of frog, although the variation is not great. The use of the mean, which is $2\frac{7}{10}$ for 3 ft. 0 in. gage, $3\frac{2}{10}$ for meter gage and $4\frac{3}{10}$ for 3 ft. 6 in. gage, furnishes fair results in practice. It will be observed that the difference in length between the lead rail and the turnout arc is likewise the quotient found in dividing 12 in. by the frog number that most nearly represents the resultant degree of the connection.

Degree of Curve.—The degree of curve in narrow gage turnouts follows the same ratios as in standard gage, but the curve of the No. 6 connection for 3 ft. 0 in. gage is 50 deg., for meter gage 40 deg., and for 3 ft. 6 in. gage 30 deg. The rules for lining at the heel of the frog and for designing the bill of timber may be readily adapted to use in the narrow gage.

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Where 11 ft. 0 in. centers of tracks obtains and the equipment is as wide as 9 ft. 1 in. and of a total length of 51 ft. 0 in., the use of curves greater than 40 deg., or 147 ft. radius, is undesirable and the No. 6 frog should therefore not be employed in less than meter gage. The combined nosing and overhang of such equipment while making parallel movements through crossovers with curvature of that degree would limit the track centers to 12 ft. 0 in. The presence of one of these features alone would reduce the clearance on 11 ft. 0 in. centers to a bare margin of safety.

Permissible Speeds.—The speed permissible through standard gage connections has been determined as equivalent in miles per hour to double the frog number, but by reason of the smaller bearing area of the tie and the increased impact due to higher center of gravity and greater oscillation in narrow gage, a speed of no more than once the frog number is allowable.

34. GRAPHICAL METHOD OF LAYING OUT SWITCHES.

It is practically impossible to establish a complicated layout of switches upon the ground with the transit instrument, and whenever such a feat is attempted nice work is required on the part of the foreman to harmonize the arrangement. A much more satisfactory solution of the problem is found in the graphical method. With good templates a layout may be plotted exactly to scale, and if the scale is large enough, (but not so large that the radius of the curves overruns the available scope of the curve templates), scale measurements may be taken at in-

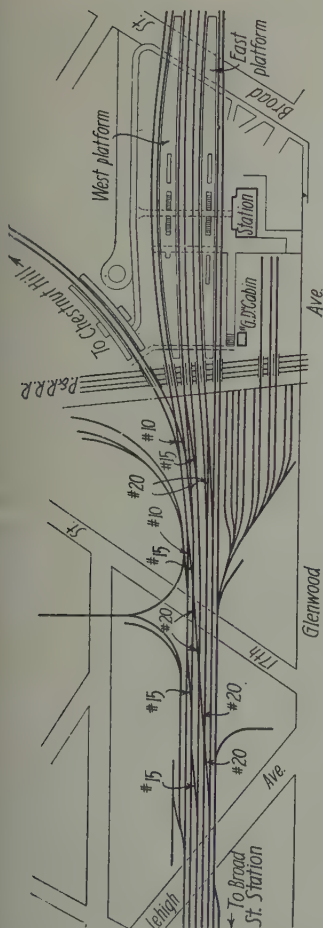


Fig. 13. Arrangement of Switches at North Philadelphia Interlocking; Layout Installed by Means of Measurements Scaled from a 1 In. to 32 Ft. Plan.

tervals across the layout and from these, and the linear measurements for the practical lead, a fairly correct location can be made.

Even when turnouts as high as No. 20 are employed it is possible to use a scale as great as 1 in. to 16 ft., but in most cases, if the plotting is exceedingly accurate, a scale of 1 in. to 32 ft. is sufficient. The architect's scale is preferable to the engineer's scale for this purpose, as dimensions for switch connections are generally, and should always be, in feet

and inches rather than tenths, especially because the men who apply the switch material can best use inch

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rule. The diagram shows a layout that was successfully installed by means of measurements scaled from a plan drawn to a scale of 1 in. to 32 ft.

35. HINTS FOR LAYOUT.

A specific arrangement, which by a proper selection of location may often be made to apply for such important points as the end of double track, or the ends of passing sidings, is the establishing of the point of switch of the turnout at the beginning of a curve, when there will be continuous simple curvature for both sides of the connection and the superelevation will be common to both tracks. This is of very great advantage to the operating efficiency of the turnout.

In congested districts it is not always possible to employ a simple ladder and resort may be necessary to lap connections. This should never be three-throw switch work, which is in the nature of special design requiring interest charges for infrequently used duplicates. Lap connections can always be designed which will employ regular stock patterns of frog and switch material.

It is often advantageous, particularly when the crossover is on a curve or partly on a tangent, to plan the crossover with dissimilar frogs. If, for example, the available space on a 3 deg. 30 min. curve will permit of no longer crossover than a No. 10, a better alinement will be obtained by the use of a No. 8 turnout from the outside and a No. 12 turnout from the inside of the curve, the resultant curvature being 8

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deg. for both ends; whereas one end of the No. 10 crossover would otherwise have been 11 deg. This plan eliminates the tangent between the frogs, but for low speed movement this is not important. The arrangement, however, has limitations, as it is not possible in ordinary track centers to mate any frog with one that has a number more than 60 per cent. greater; that is, a No. 8 and a No. 12, a No. 10 and a No. 15, a No. 15 and a No. 20, or a No. 15 and a No. 24 are limiting combinations.

In deciding what number of frog to employ it is necessary to consider not only the general question of curvature but also the question of clearance with adjacent tracks. Thus, a No. 6 connection in tangent track adjoining a main track with 12 ft. centers is hardly a safe selection. The "nosing" of the longest passenger equipment while passing through such turnouts furnishes bare clearance with the traffic running on the adjacent track, and if curvature and superelevation enter there may be actual interference.

A similar question is involved where two switches leading from a double track are placed exactly opposite. In such a case when simultaneous movements are being made from the main line into both turnouts the clearance is doubly affected. To avoid this disadvantage the location of the switches should be staggered at least 10 ft. By reason of the vital need for ample clearance in all train movements and because of the maintenance difficulty as well as the commercial scarcity and consequent high price of

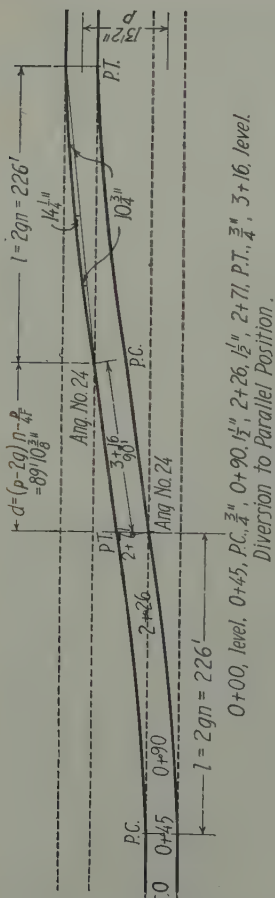


Fig. 14.

timbers above 22 ft. in length, the practice of placing crossovers for parallel movements exactly opposite is being discontinued. They should be so located that each will have independent long timbers.

It is usually considered objectionable to locate crossovers on a curve but there are advantages which weigh well with the disadvantages. Thus, a No. 20 crossover on a 1 deg. 40 min. curve is a 3 deg. 20 min. curve on one end and tangent on the other. Although the curvature is twice as sharp as for a No. 20 from straight track, there is the compensating feature of the super-elevation of the main track curve, which being designed for high speed

on the main track is ample for the reduced speed through the sharper curve of the turnout.

Diversion to Parallel Position.—The theoretical

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design of a crossover may be employed for the rather common case wherein a track is diverted to a parallel position, usually the regular distance for track centers, although the distance may be a different one. Exact theoretical lead will be employed, which is equal to twice the gage multiplied by the number of the frog, and the rule for distance between the frog points will apply except that it will not be reduced by inches equal to the frog number. The lining of the curves may be done by offsets in the manner elsewhere explained; or, alternately, by drawing a string between the theoretical point of switch and point of frog and lining the track with an ordinate of $14\frac{1}{4}$ in. at the middle and $\frac{3}{4}$ of this or $10\frac{3}{4}$ in. at the quarters. Proper correction would need to be made if the proposed layout were on a curve. In that event the principal point to be observed would be the designing of the crossover with dissimilar frogs, which might even be of unusual numbers, so that the curvature of the two parts of the arrangement would be equal.

For a diversion through 13 ft. 2 in. distance between parallel tangents the equivalent of a No. 24 crossover with 90 feet of tangent between the curves is quite favorable. The curvature is 1 deg. 05 min., and with the use of $1\frac{1}{2}$ in. superelevation, which may be run off one-half on the curve and one-half on the tangent at a rate of $\frac{1}{2}$ in. to 30 ft., a speed of 50 miles per hour might be established.

CHAPTER XI.

PRACTICAL CONSIDERATIONS IN INSTALLING TURNOUTS.

36. ORGANIZATION.

Training Gangs for Switch Work.—The correct and expeditious placing of switch connections requires special qualifications, and any important operation of that character should be assigned to a gang expert in such work. The foreman should be one whose ability and taste in the refinements of switch installation have been demonstrated beyond question, and it is almost equally important that the major part of the gang should be capable workmen, since every operation requires not only skill but despatch.

Each supervisor's division should have at least one such gang available and other gangs should be in process of development to undertake such work when the occasion arises. For this object the simpler items of switch construction, such as new switches in private industry tracks, unimportant spurs in isolated situations, etc., should be delegated to the less experienced gangs, and their efforts should receive greater assistance from the supervisor. An unskilled gang can often be combined with an expert one in a switch operation, with excellent advantage to the former and without detriment to the general result.

Number of Men Required.—The number of men needed to constitute an efficient gang for the expedi-

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tious application of a switch connection, in a busy main line over which passenger traffic is carried at speed and in considerable volume, is not far from 24, exclusive of the foreman and his assistants. A less number is not able to handle the heavy work periodically necessary, and a greater number cannot labor to advantage in the restricted space. Two of the laborers should be men qualified to act as flagmen; a third, whose dependability is unquestioned, should watch for the approach of trains and convey proper warning; a fourth is needed to carry water and look after the tools; at least ten should be capable spikers and all should be useful in general lines of work. Each individual of the gang should have a specific duty to perform when the rush is on after the use of track has been given. The entire gang should fall into their allotted duties naturally and without the necessity of a preliminary line-up.

Developing Quickness of Action.—The men who flag should be alert to display the warning signal the moment the need is communicated, and should be trained to hold the banner against trains until unmistakably recalled. The waving of a red flag by the foreman at the immediate location of the work should be the notice for the men to start the work, and should also be the signal for the distant flagman to act.

Only when its movements are automatic and instantaneous can the gang be regarded as well organized. Any members who are slow or awkward or inclined to run into the way of danger should be promptly eliminated. The efficient foreman is able to indicate

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his instructions with a word, even a gesture, and he should exact instant obedience. With the consciousness that his practice is founded upon correct rules, he proceeds unerringly and his confidence inspires efficient co-operation from his men.

37. SPECIAL TOOL EQUIPMENT.

Besides the ordinary stock tools, the switch gang should have a rail dolly to move rails quickly from place to place; a rail saw to cut rails of proper length, (a very frequent necessity in extensive interlocked switch work carrying specific locations of insulated joints); pneumatic tie tampers and rail drills for use whenever access to a compressed air line is possible; a hydraulic rail bender to break rails for temporary connections, to bend stock rails for accurate adjustments with the switch rail, and in certain cases to bend the rails to conform with the curve of the sharper turnouts; and, not least in importance, a tool which may be called the pick adze, because generally made in the blacksmith shop from an ordinary tampering pick, which is exceedingly useful in respiking for cutting about spikes to facilitate their withdrawal.

The track gages employed should be only those whose accuracy has been tested and a steel tape divided into twelfths is practically a necessity for nice work. A metallic tape is good enough for measuring the lengths of the switch ties or for laying off their places in the connection, which should always be done by continuous measurement, particularly in slip switch work. A ball of twine for lining should

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not be lacking. As the switch gang is a floating one a substantial tool box is required.

38. DETAILS IN THE DESIGN.

Avoiding Unusual Lengths of Rail.—The practical length of lead having been determined so as to employ whole stock lengths of rail wherever possible, the turnout arc should be made of the exact increased length necessary by cutting a longer stock length. This practice is important because the presence of unusual lengths of rail in the main track is very undesirable, and because the cutting of a rail if not properly done introduces an elevation of the surface which is noticeable in riding. However, this latter objection may be overcome by using the rail saw, or by scoring only the perimeter of the base in cutting, which nearly invariably furnishes a square break with the smoothness of the rail surface undisturbed. It is a distinct advantage to make the rail units in the turnout arc as few in number as possible, especially in the sharper turnouts. The signal requirement for a 5 ft. staggering of block joints can usually be met by proper selection from the odd stock lengths of rail available.

Arrangement of Joints.—One of the essential details in switch work is a nice arrangement of the joints. Whether housing of the switch points is approved or not, the joints in advance of the point rails should follow a uniform standard. The joints in the two stock rails admit of little staggering, but this should be such that each joint has independent tie

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support. With the longer switch points no intermediate ties between the joints are possible unless long stock rails are used, the utility of which is doubtful.

Assuming 33 ft. stock rails and a 30 ft. switch, the joint on the main stock rail should be the one nearer the point of switch, because this will enhance the efficiency of the joint at the other end of this rail, which is a part of the main track structure. The distance in advance of the point of switch to this joint should be 4 ft. 11 in., which allows sufficient space ahead of the switch for the splice bar, and spaces the joint at the reverse end of the rail one tie-interval from the heel of the switch. The joint of the turnout stock rail should be 8 ft. 3 in. in advance of the point, which spaces the other end of this stock rail three tie-intervals from the heel of the switch. The preservation of this uniform arrangement is desirable even though it may generally require the introduction of shorter rails into the main track, and even though, if space be limited, it may necessitate a resort to the shortening of the lead within the allowable limits. This uniformity is of course a necessity when stock rails housed at the mills are employed. As switches which occur together are usually part of a route across multiple track systems, the suggested arrangement would be duplicated for the adjoining switch with the result that the two switches would be separated 13 ft. 2 in., or 46 ft. 2 in., which unquestionably are very favorable distances.

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The elimination of joints from guard rails, desirable at all times but essential with the employment of guard rail clamps and their fillers, is a well known requirement of nice work. The further arrangement of joints should be such as to use the shorter, odd lengths of rails supplied with all rail orders to the usual amount of 10 per cent, the presence of which at other points is undesirable. To obtain the best line, no rail length less than 15 ft. should be employed. All rails should be drilled and the joints full bolted and tightened before final line is established.

Bend in Stock Rail—The point at which to introduce the angle in the turnout stock rail is one concerning which practice varies. A computation of the distance from the actual to the theoretical point of switch, assuming the former to be generally $\frac{1}{8}$ in. thick, shows it to vary between 3 in. for a 10 ft. switch and 8 in. for a 30 ft. switch. It is not possible to bend a rail to an exact angle at any point and the proper location of the bend, for the bending apparatus available, is readily found by trial for each length of switch. This distance will usually be determined as 6 in. for a 10 ft. switch, 9 in. for an 18 ft. switch and 12 in. for a 30 ft. switch. The set should be made in the stock rail leading to the less important track, even though this would normally be the tangent from which the turnout seemingly springs. The important feature is to provide a smooth route for the faster or higher class traffic.

Spacing of Ties—The spacing of the switch ties is a detail which should have careful attention. In

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main running tracks carrying fast-passenger or heavy-freight traffic with timbers of about 9-in face, a spacing center to center of $22\frac{1}{2}$ in. should be employed, which is equivalent to 18 ties to a 33 ft. rail, and is equal in bearing area to 20 ties of a width averaging 8 in. This spacing is a convenient one because in the application of the rule for computing the bill of switch timber the increments become even fractions of an inch for the three most used of the higher numbers of frog, viz., $\frac{3}{8}$ in., $\frac{3}{4}$ in. and $1\frac{1}{8}$ in. for a No. 20; $\frac{1}{2}$ in., 1 in. and $1\frac{1}{2}$ in. for a No. 15 and $\frac{3}{4}$ in., $1\frac{1}{2}$ in. and $2\frac{1}{4}$ in. for a No. 10.

While this spacing would appear somewhat difficult of application by continuous measurement for some foremen, facility may be acquired readily in adding 2 ft. and dropping back $1\frac{1}{2}$ in. each tie space.

In private sidings and yards a spacing center to center of 27 in. is sufficient, which is equivalent to 15 ties to a 33 ft. rail or equal in bearing area to 17 ties of a width averaging 8 in. While this may seem excessive for such places from the standpoint of support for the rail, it is none too much to fully meet the requirements in maintaining the alinement. This spacing renders the increments in computing the bill $1\frac{1}{8}$ in. $2\frac{1}{4}$ in. and $3\frac{3}{8}$ in. for No. 8 and $1\frac{1}{2}$ in., 3 in. and $4\frac{1}{2}$ in. for No. 6. It is, of course, quite a simple procedure in laying out the spaces to go forward 2 ft. 3 in. each time. The spacing in both cases would have to be modified in the event that hewn switch ties were employed.

Location of Switch Lever—It is desirable that

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non-interlocked switches in main running tracks should have the ground lever so placed that when set for the main track the rod connecting the switch with the switch stand is in tension. For switches that connect ordinary sidings, the switch stand, if possible, should be on the right-hand side of the switch in facing the connection. Wherever a siding connects with a main track a derail should be installed in the siding at the clearance point to prevent cars being moved beyond that point by the wind, by error of train crews or by malicious persons, when no lamp or other indication would warn a train approaching on the main track of the danger.

CHAPTER XII.

METHODS IN INSTALLING AND MAINTAINING SWITCHES.

39. SIMPLE CONNECTIONS.

The location of the connection having been selected and the details of the design determined, the main points of the lay-out should be marked upon the rail. These include not only the point of switch and $\frac{1}{2}$ in. point of frog, but all the joints proposed throughout the lead. Preliminary establishment of the joints is essential to the placing of the switch timbers in their correct positions, avoiding the need for respacing.

The Guard Rail—The timber having been installed, the main-track guard rail should be applied. It should be well secured and the proper width of flangeway provided. This width is $1\frac{3}{4}$ in. when the gage of the track is 4 ft. 8 $\frac{1}{2}$ in. and $2\frac{1}{4}$ in. when the gage is 4 ft. 9 in. Frogs of No. 6 and lower usually have the 4-ft. 9-in. gage. After the frog is placed care should be taken that the guard rail gage of 4 ft. 6 $\frac{3}{4}$ in. is observed. This is the distance from the gage line of the frog to the gage line of the guard rail. It does not vary in amount for different gage of the track. For convenience the guard rail gage should be measured upon some part of the track gage.

For the greatest effectiveness, a full equipment of guard rail clamps and guard rail tie plates is necessary. The tie plate guard rail fastener is another

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useful accessory in the support of the guard rail. No variation in guard rail gage is permissible, and the longitudinal position of the guard rail should follow the standard closely.

The Frog and Lead Rails—Along with the frog the full lead rail including the switch point is usually applied. When the main track point only is in place it should be both spiked down and clamped to the stock rail and when both points are in, but not connected to the switch stand, the turnout point should also be wedged away from the main rail. If the exact heel gage is preserved and the bend made in the stock rail at the proper place, the switch point will set up close to the stock rail through the whole length of the tapered section. When the switch is thrown the corresponding point will similarly be in contact with the main rail.

Mating of Switch Rail and Stock Rail—Accidents have resulted from foremen making the mistake of putting in a switch point of different section or weight than the rail in the track. A much worn switch point in combination with a full section stock rail might also cause an accident. The stock rail should never be chipped with the cutter to make the point set up close, as this practice renders the rail more liable to fracture.

When Protection is Required—There are certain rules for renewing ties and rails in main tracks which must always be observed, and these apply equally in the installation of frogs and switches. The

rule specifies that any condition which interferes with the safe passage of trains at full speed is an obstruction and must not be attempted without full protection in both directions.

An obstruction is considered to exist when more than one tie in face is removed, or more than four ties are removed in any rail length, or the ties adjacent to the one removed are not fully spiked and tamped. Also when the spikes are withdrawn from more than every other tie on both sides of the rail, or the joints have less than two bolts in place with either one of these not fully tightened. An inferior compromise joint or one not properly applied, which allows a drop in the surface or an offset in the gage of more than $\frac{1}{8}$ in., would constitute an obstruction. A tightening of the gage more than $\frac{1}{4}$ in. or a widening more than $\frac{3}{4}$ in. from the standard would require protection. In regaging when more than every other tie is unspiked and the spikes removed on the inside from more than four consecutive ties there is an unsafe condition. In all work care should be taken that trains are passed with an ample margin of safety.

40. SLIP SWITCHES.

As the various parts composing a slip switch are made to the exact dimensions prescribed by a standard plan, the utmost care is necessary in applying the material to assure correctness in every detail. The linear measurements, particularly for the longer slips must always be made with a steel tape and for the

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nicest work the tape should be one that has been tested for its accuracy. It is not too great a refinement to adjust the measurements for temperature variation. Steel tapes are not infrequently as much as $\frac{1}{2}$ in. in error, and extremes of temperature may balance this error or introduce a further error, which in a No. 20 slip nearly 200 feet long might cause a total error of 4 in., which would of course be inadmissible.

Measuring Dimensions—Axis of Slip—All linear dimensions should be measured along the axis of the

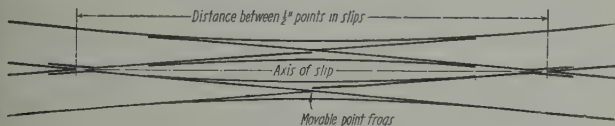


Fig. 15. Diagram of Slip Switch.

slip, a line connecting the theoretical points of the end frogs. It will be found useful to sketch this axial line accurately upon the ties for the triple purpose of laying off the detailed linear dimensions, for squaring the switch ties as they are applied and for lining the ends of the timbers, which for a double slip crossing will be symmetrical about this line.

The position of one of the connections leading to the slip will determine the location of the adjacent end frog. While the standard plan will indicate the distance between the end frogs, measured along the axis, a somewhat more convenient determination is possible. By multiplying twice the gage by the frog

number the distance between theoretical points of the end frogs measured along the main rail is obtained. The second frog may thus be located readily, proper care being necessary in squaring across the track.

The alinement and gage of the track being correct, the axis may then be established and its middle point will be the center of the slip. From this point all measurements in both directions will be made to locate the points of the movable point frogs, the points of the slip switches and the several timbers of the slip.

Tie Spacing—The distances between centers of ties are given consecutively, but to attempt to lay off these by successive measurements would introduce cumulative error which at the ends of the slip might amount to several inches, and this again would be out of the question. The distances from the center of the slip to each tie should be calculated and the location made by continuous measurement along the line previously laid down for the axis of the slip.

As the ties that properly belong with the slip vary in length only between the limits of 10 ft. 0 in., which is the nominal length of the tie at the middle of the slip, and a length which equals the track centers, and while the number of ties within these limits for each half varies from 17 for a No. 6 to 55 for a No. 20, the increments will be nearly uniform and the ends on both sides practically in a straight line; thus no difficulty whatever need be experienced in applying the necessary timber for any slip set. It should be

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noted that the last short tie has a similar location with reference to the end frog in the slip that it holds in reference to the frog of a plain crossover.

Main-Track Alinement—In the installation of any switch connection the importance of obtaining a correct alinement for the main track is well known, but the absolute necessity for this precaution in the placing of slip switch work cannot be too strongly stated. While a perfect alinement of the slip ladder is desirable and will follow if the installation is correct in all its details, the essential feature is to preserve the integrity of the main-track alinement. If the line is a tangent, it should be established by the engineer and this determination be faithfully followed. If the slip is on a curve, the method of ordinates should be used in the lining, first with a 100-ft. string to correct the general line and then with a 50-ft. string to obtain a fine detail line. This will be a final determination because the timbers having been placed in their exact permanent locations no shifting or other work causing distortion will be necessary.

As mechanical work cannot in the nature of things be perfect, some detailed adjustments may be necessary even with the most faithful adherence to the standard plan in the application of the material. This correction should not be attempted until a final surfacing has been given, as frequently defects that appear as line are really caused by imperfect surface.

Slip Switch Accessories.—Since accuracy in the installation is unavailing without the means of main-

taining the exact relations of the parts, heel blocks should be provided, with the bolts connecting both lines of rail; anti-creeping straps should be supplied, anchoring the heels of the slip switches and the heels of the movable points against creeping in either direction; and every track leading to the slips should be amply equipped with anti-creeping devices.

A better practice has developed in the matter of applying the adjustable rail braces used in connection with the bridle plates. It formerly was the practice to secure the braces to the bridle plates by lag screws let into the switch tie, but the hold was not substantial and the screws frequently worked loose. It is now the practice to use screws which enter the bridle plates where additional thickness of metal has been provided, to admit which the tie must be dapped or adzed out about 1 in. It is necessary to fit the plate neatly into its seat so that moisture may be excluded as far as possible.

Gradient—A very distinct error in switch economics, and one which as a rule is not fully appreciated, is the placing of an extended layout upon a broken grade. This is particularly disadvantageous when the layout is at the marked depression made by two sharply changing gradients and the effect is most adverse in the case of a slip ladder by reason of its greater length. The ideal location of an interlocking is with a single grade continuous throughout its limits. The saving in maintenance, both to the signal and track forces, through the ideal arrangement, is quite measurable.

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The aesthetic feature is likewise greatly enhanced by such provision.

41. MAINTENANCE OF SWITCH CONNECTIONS.

Removing the Ballast—Whether preliminary to the installation of a new connection or to the renewal of the timbers in the old, it is of decided advantage to remove the ballast entirely to the bottom of the ties throughout the length of the connection. In no other way can economy of time be effected in the general respacing of ties that occurs both in the original application and in renewal. An exception might be made when spotting of switch timbers only is being done; but this excellent and generally prescribed rule for renewal is seldom practicable, as the timbers are almost certain to be in a fairly uniform state of wear and decay. The entire removal of the old ballast assures a cleanly ballasted track, which is of great benefit both to the riding of the connection and to the life of the ties.

Surfacing—The tamping should receive especial attention, as the comfortable riding of switch connections is the exception rather than the rule. The pneumatic tie tamper will be found of especial utility in such surfacing. The practice of elevating the switch rail for safety introduces a very neat problem for the expert maintainer. A plotted profile of a succession of closely bunched switches in a main track is calculated to instill despair of fine results in riding, but it is well known that such results can be attained. In general, the joints at the heel of switches and block

joints require the hardest tamping and the most frequent surfacing.

Lining—Proper line seldom obtains through main track switch connections because enough pains were not taken in the original installation. Correction can sometimes be made by separating the main track and the turnout between the switch and frog into independent units by unspiking the respective tracks upon alternate ties, and throwing with the bars, completing the adjustment by careful spike lining. The latter should always be done by widening the gage rather than narrowing it. Care must be taken at the frog to preserve the correct guard-rail gage at all times that service is permitted.

Accurate line through the connection having been secured by careful attention to the rules given, the preservation of perfect line can be assured only by a faithful use of tie plates, and the rule should be made imperative that every switch tie should be plated. It is doubtful whether treated switch ties, which are frequently of inferior soft woods, are safe, for a single train movement, in connections of heavy service, without the addition of tie plates. The use of white oak for all switch ties is a desirable, but probably unattainable, ideal. The troublesome maintenance question caused by the running of switches can be largely met by a generous use of anti-creeping devices, both throughout the connections and for some distance along the main track in the opposite direction to that of the traffic.

Attention to Slide Plates—The cleaning and lubri-

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cation of the plates and other bearing surfaces of switches and of movable point and spring rail frogs, is a very important item of maintenance. The prevention of sanding over switch connections relieves the maintainer of much useless labor, and the road of much unnecessary expense for oil consumed. At the approach of freezing weather it is generally customary to remove the ballast from the tie spaces at frogs, switches and guard rails to facilitate the removal of snow and ice.

Inspection and Test—Frequent inspection of switches, both by the track foreman and signal maintainer, is necessary to guard against lack of adjustment, which might result in accident. These inspections should be made monthly for general condition, bi-weekly for detail defects and daily whenever possible to detect small irregularities which might assume dangerous degrees in brief time. The limit of safe wear is a variable one, but as regards the frog, is about reached when the half-inch point is worn $\frac{1}{2}$ in. below the original top surface of the frog. As regards the switch, the limit of safe wear can only be determined by the judgment of the inspector. Stock rails represent only nominal maintenance expense and should be kept in first class condition at all times.

The condition of the various members that compose the switch connection and the adjustments maintained are of such vital importance that detailed tests are prescribed on all roads and, in order that these tests shall not be perfunctory, it is cus-

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tomary to require that they be conducted jointly by a representative of the signal department and of the track department and that they be made on or about certain dates.

To facilitate the rendering of the periodical reports each switch or crossover in a given interlocking is numbered and each switch rail distinguished by a letter. The opening at switch points is prescribed by the standards of the road and is usually 5 in. The opening at which the switch lock will foul when the switch is closed is fixed by the signal practice of the road and is generally $\frac{3}{16}$ in. Terms are indicated to describe the condition of the switch points, stock rails and ties as *good, fair, bad*. The gage is measured and any other features are noted under the head of remarks. The signal department's responsibility is in the adjustment of the interlocking connections, that of the track department in the condition and general maintenance details of the several members of the switch connections. As the signal department does not have any concern with the frogs or guard rails, these are covered in another test made by the track foreman alone.

The switch test develops the exact condition of the switches and their connections at intervals, which for the best practice is every two weeks, and not only safeguards the traffic but supplies an excellent defense in the event of an accident from some obscure cause. These tests by the signal and track maintainers are invaluable, but there is still necessary the occa-

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sional inspection by the signal supervisor and the more frequent detailed inspection by the track supervisor.

The inspections by the supervisor of track should take in the physical characteristics of the entire layout, and his notes should be full and be recorded in permanent form. He should especially observe the points of frogs to note if they are being touched by passing wheels as indicating a loose guard rail gage, and he should then try the gage and order the necessary correction. This test is especially important at crossings which require constant attention to gage. The condition of all switch points should be noted and also, as far as possible, their adjustments when thrown for a movement. The two rails should be sighted to discover any tight gage that may have developed, as the movement of the rails through creeping sometimes introduces a tightening of as much as $\frac{5}{16}$ in., whereas $\frac{1}{4}$ in. is the most that is entirely safe. It should be observed particularly whether the joints at the heel of the switches and the insulated joints are properly surfaced, and whether the full complement of bolts is inserted at the rail joints. Any points unfavorably reported by the maintainers should be examined.

The inspections made by the higher officers are usually by proxy, many divisions having a special-duty man who makes such tests for the division officer; and there is an occasional test by the representative of the engineer maintenance of way. The division superintendent and his staff make superficial

observations of the interlocking layouts about once in every three months when the various towers are being inspected as to their sanitary condition.

The record of switch inspection and test is very important in view of the insistence of the road and civil authorities for exact information in the investigation of derailments. One has but to walk over a few miles of railroad to note the many parts of cars that drop off in passage, and to wonder that so few of them drop into the throats of frogs and switches. Cases where such obstructions have caused derailment are not rare, but the proof of the occurrence is seldom found and the record of the exact condition of the switch connection may be the needed evidence to clear the maintenance department.

42. PRACTICE IN OPERATION.

Speed Through Main Track Turnouts—The important question of what classes of power should be permitted to operate over certain numbers of switch connections and what speed such operation should carry is best determined from the degree of curvature. A speed of 30 miles per hour has been found entirely satisfactory through No. 15 turnouts from tangent track or from the inside of very light curves, but the resultant curvature for such operation should not exceed 3 deg. 30 min. This allows a theoretical unbalanced elevation of 2 in. which is only permissible in switch connections where the effect of traffic shifting is practically eliminated by the character of the track

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structure. This speed will be indicated by the middle arm of the signal.

With the increased use of higher numbers of frog than No. 15, it is desirable that the increased speed made possible be fully realized. The design of the switch operates to restrict the speed except through the route that is given preference in the adjustment of the stock rail. If the two routes are given equal advantage, a speed of 40 and 45 miles per hour, respectively, may be permitted through No. 20 and 24 connections. For such use the top arm would be given and a general order would prescribe the limiting speed, and some type of speed indication board would be placed to call attention to the restricted point.

Speed in Yards—As the curvature through yards will vary greatly, the only safe rule is to limit operation to the highest speed that the sharpest connections allow. In ladders, which are usually No. 8 but occasionally No. 10, the allowable speed might be fixed at 15 miles for the first and 20 miles for the second, provided the presence of a curved main line did not adversely affect the curvature too greatly. In the case of interlocked crossovers it is customary to regulate the speed by the signal indication. As the lowest arm permits a speed as great as 15 miles per hour, it is necessary when movement should be made at a slower speed to indicate by legend upon a standing sign board the speed that may be used.

The limit of curvature that may be passed by the

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common types of road engine is the curve of a No. 6 connection from tangent track, or 250 ft. radius. Some types of road locomotives may be forced around a very much sharper curve, but it is generally recognized that a margin of at least 50 per cent is proper for absolute safety.

Location of Switch Lamps—The location of the switch lamp is of direct concern in operation. Its distance from the track is important as a safety consideration. Whenever practicable it should be at least 4 ft. 7 in. distant from the gage of the nearest rail. If placed closer its height should be such that a brakeman clinging to the car would not have his clothing caught and possibly be dragged down with serious result. This is usually accomplished by having the lamp stand separate from the switch stand. Such an arrangement has a still further advantage as affecting safety in operation, because the lamp would then more certainly indicate the position of the switch. In the event that the switch stand were damaged the lamp, if attached to it, would generally give no indication of the defect.

Numbering Switches—In long ladders a great advantage in operation is secured by a plain designation of the switch leading to each individual track. Time is frequently lost in seeking the right switch, and not infrequently even more time is wasted in correcting a false drill movement occurring through error in choosing the switch. This may be avoided by the addition of a target to the switch stand carrying a

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designating number or letter, so placed that the light from the switch lamp will fall upon it, and slightly inclined so the brakeman riding the car will receive information as to the track he is about to go upon. The banner should not be a fixed board that one might stumble over, but should be integral with the switch stand.

Care of Switch Lamps—The degree of care used in attending to switch targets and lamps is of great consequence in operation. The targets require repainting at least every six months, and should be kept bright and clean by washing as may be necessary in the intervening time. The lampman should always make sure that there is enough oil in the fonts to keep them burning the required time. When the lamps are lighted it should be seen that the wicks are properly adjusted at the proper height to give a good light without smoking, and that the lamps are lined to give the best possible indication to trains.

PART III—SIDING LOCATION

CHAPTER XIII.

SIMPLIFIED FIELD WORK.

The supervisor frequently has need of a simplified method for laying out the curves of a siding, either at the time the preliminary survey is made, or later when the siding is about to be constructed. In the first case the layout may be required to immediately show the applicant the main features of the alinement, in the second case the service of the engineer may not be available, or the use of an instrument be unobtainable. In either event a tape line location may be the only one possible.

Doubtless some cases will require instrumental work, and it is then useful to know how the processes can be simplified, for the corps will usually consist of the supervisor or his assistant and a trackman or two. The problems in instrumental layout are, of course, not intended for the track foreman.

It is believed that many of the simpler cases of siding location can be met by the foreman himself with the use only of a tape line. Most foremen, as well as supervisors, carry with them at all times a 5 ft. extension rule and 50 ft. tape line, and many also carry a 100 ft. length of string to correct the general line of curves. By the aid of the simple rules of geometry and with the accessories mentioned it will be possible

for the foreman to dispose of many cases and often avoid the necessity of the supervisor making a special visit to the location. For this object the first two problems which follow are explained in greater detail, and examples are given to illustrate the several rules.

The matter is greatly simplified by the fact that the right-of-way line is nearly always parallel with the tracks, and the building which fixes the location of the siding is also usually parallel, and the siding therefore either parallel or at right angles with the track. But even for those cases where the siding is not parallel or at right angles with a tangent main track, a special solution is possible which is not unduly complicated and which can be comprehended by many track foremen. It is not claimed that any new theorems have been developed, but it is claimed that the solutions offered are not to be found in any of the field books.

It will perhaps be thought by some that in neglecting the tangents introduced into the siding curve by the straight switch and frog, accuracy is being sacrificed; but it will be found that for turnouts above No. 5 (and those below have been practically eliminated by the operation of the Safety Appliance Law), no sensible error will result from this source. Stakes need not be set at either the point of switch or the point of frog, but the location of these should be indicated by marks on the rail, and care should be taken that the $\frac{1}{2}$ in. point of frog is always understood.

43. PROBLEMS IN TAPE-LINE LAYOUT.

Problem 1—The simplest case is that of a siding

parallel with a tangent main track and fronting a building, the location of which fixes the maximum offset distance. There is no practical need, nor is there usually the space, to introduce any tangent between the curves. In order to render the physical conditions as favorable at the point of reverse as at the beginning and end of the reversed curve, it is quite an advantage to make the two curves somewhat flatter at the reversing point and this may be done by using the formulae of the parabola. While this increases the length of the curve somewhat, the extension is not more than a few feet even for an extreme case.

$$l^2$$

The formulae symbolized are: $p = \frac{l^2}{2R}$ and $l = \sqrt{2pR}$

$\sqrt{2pR}$, or expressed in words signify that for a chosen distance from the point of curve along the tangent, *the offset is equal to the square of the distance divided by twice the radius*; or, conversely, for a chosen offset from the tangent, *the linear distance is equal to the square root of the product of the offset multiplied by twice the radius*. (The field books employ these formulae for staking out a circular curve by offsets from the tangent and chords produced. The value of the offset from the chord produced is twice that from the tangent, and the distance used is measured as a chord of the curve, instead of a length always laid off along the tangent. The method is unsatisfactory because the operation of successively producing the chords renders the process subject to cumulative error.)

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By the use of the formulae in the manner first indicated, the distance from the end of the curve to the reversing point, and from the reversing point to the point of switch may be obtained at once. These distances will be equal, if the two curves are of equal radii, and the reversing point will be midway between the line of the main track and of the siding. (Whether the curves be of equal radii or otherwise, this point will lie in a line joining the two tangent points.)

Any number of intermediate points on both curves may be set after computation of the offsets. The off-

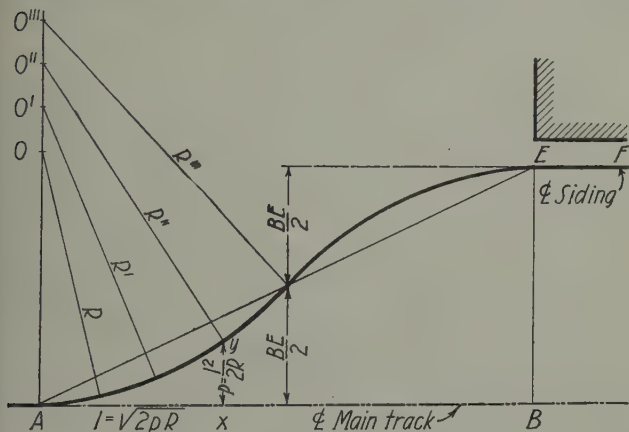


Fig. 16. Problem 1, Siding Layouts.

sets from the main track for the second curve will be obtained by subtracting the offsets calculated for the first curve from the whole distance between the siding and main track. Thus all the measurements will be made from an actual base line and every source of

error in the field work eliminated. It should be noted that the several offsets vary as the square of the linear distance. If the distances selected are in a simple ratio, the square of this ratio multiplied by the first offset will supply the other offsets with a considerable saving in computation.

For example, assume that the building is located 15 ft. beyond a right of way 50 ft. wide on a double track railroad, and that a curve of 500 ft. radius is to be used. The distance from the center line of the main track to the center line of the siding would then be 51 ft. The offset distance to the reversing point would be one-half this, or 25 ft. 6 in. By the formula, $l = \sqrt{2 p R}$, we find $l = 160$ ft. It will be convenient to divide this distance into 4 equal parts of 40 ft. each. By the rule, the first point being $\frac{1}{4}$ the whole distance, its offset will be $\frac{1}{16}$ of 25 ft. 6 in., or 1 ft. $7\frac{1}{8}$ in.; the offset at the 2d point will be 2 squared or 4 times 1 ft. $7\frac{1}{8}$ in., or 6 ft. $4\frac{1}{2}$ in.; the offset at the 3rd point will be 3 squared or 9 times 1 ft. $7\frac{1}{8}$ in., or 14 ft. $4\frac{1}{8}$ in.; the 4th offset will be, of course, 25 ft. 6 in.; the 5th offset will be 51 ft. 0 in. minus 14 ft. $4\frac{1}{8}$ in., or 36 ft. $7\frac{7}{8}$ in.; the 6th offset will be 51 ft. 0 in. minus 6 ft. $4\frac{1}{2}$ in., or 44 ft. $7\frac{1}{2}$ in.; the 7th offset will be 51 ft. 0 in. minus 1 ft. $7\frac{1}{8}$ in., or 49 ft. $4\frac{7}{8}$ in.; and the last offset will be the full distance, 51 ft. 0 in.

The longer offsets should be laid out at an exact right angle by knotting the string at a length of 80 ft. and holding the ends of this length at adjacent points, grasping the string at a point 30 ft. from the point

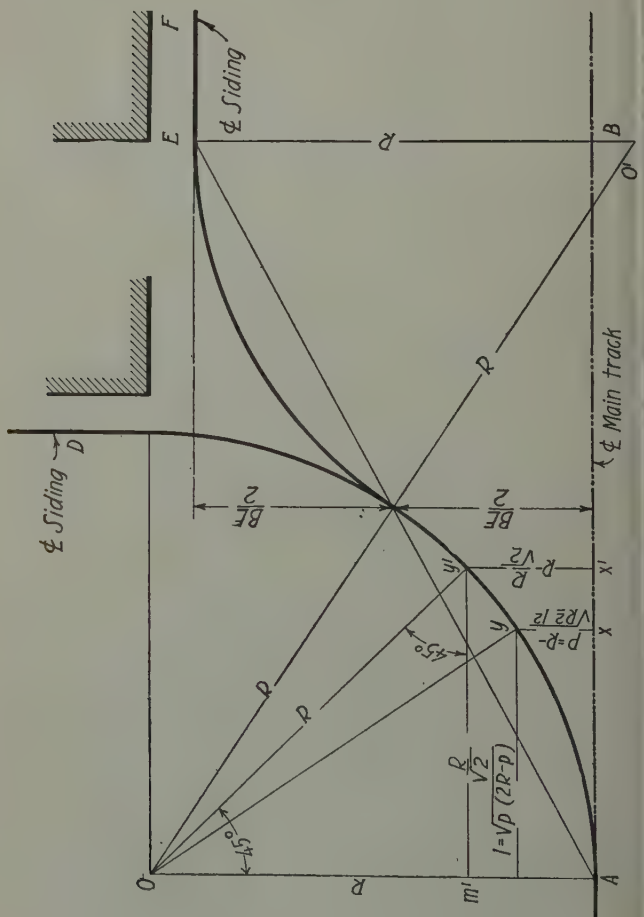
being turned and drawing it taut. This plainly furnishes the 3, 4 and 5 proportion, the main rail being the 40 side, the offset the 30 side and the diagonal, or hypotenuse, the 50 side.

This simple solution furnishes a curve which varies but slightly from a true circle, and the length of the two curves is only increased 4 ft. 6 in. It will be noted that the selection of a 500 ft. radius makes the offset 4 ft. 9 in. for a linear distance of 69 ft. Thus a No. 8 frog may readily be placed in the new curve.

When the length of radius is not absolutely determined by limiting conditions, as indeed seldom is the case, that one should be chosen which will make the offset at the point of frog equal to the gage plus $\frac{1}{2}$ in. This radius will be about 5 per cent larger than the actual radius obtaining through the lead; but this advantage is quite desirable both from the maintenance and operating standpoints.

The above solution may be used for the case of a crossover between two tracks which are parallel, but which are so far separated that tangent between the frogs is impracticable. If it is preferred to make the reversed curves circular rather than parabolic, the formulae outlined in Problem 2 for a continuous circular curve should be employed.

Problem 2—The problem of locating a siding at right angles with the main track may likewise be met by the use of offsets and with as great accuracy as the average engineering instrument will supply. It is necessary in any event to adjust the detail line of



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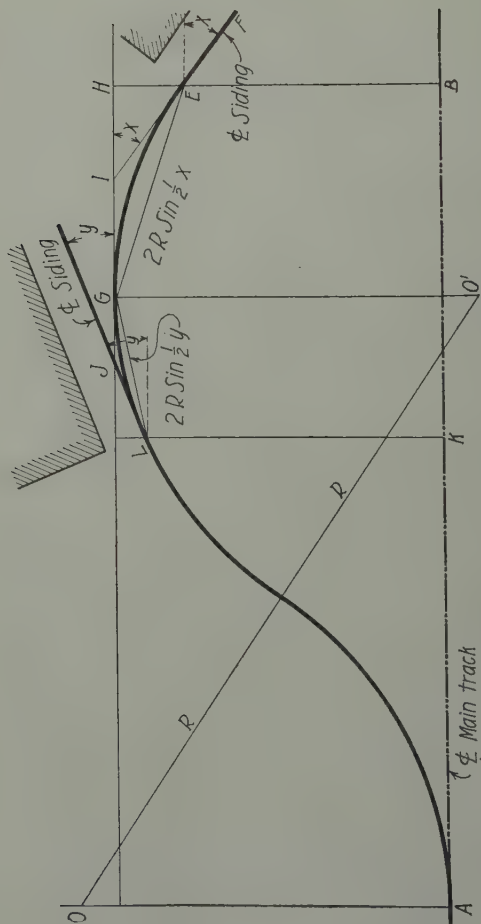
the curve when finally laid, and this can best be done with the string. The formulae for offsets employed in the preceding case will not answer for the circular curve required, and the proper formulae for such cases are the following: $p = R - \sqrt{R^2 - l^2}$ and $l = \sqrt{p(2R - p)}$.

These symbols signify that for a chosen distance from the point of curve along the tangent, *the offset is equal to the radius, minus the square root of the difference between the radius squared and the linear distance squared*; or, conversely, for a chosen offset from the tangent, *the linear distance is equal to the square root of the product of the offset multiplied by the difference between twice the radius and the offset*.

This may be used for the offsets from either end to the middle of the curve, for which point it should be noted that the linear distance is equal to the radius divided by the square root of 2, which is 1.414, and the offset is equal to the difference between the radius and this linear distance.

As an example let us assume that it is desired to connect a siding at right angles with the main track by a 500 ft. radius curve. The length of a circle with radius of 500 ft. is $3 \frac{1}{7}$ times 500 ft., or 1,572 ft. One fourth of this is 393 ft., and this will be the true length of the siding curve. The linear distance (either measured along the main track or siding tangent) to the offset from the middle of the curve is 500 ft. divided by 1.414 or 354 ft. The offset itself is 500 ft. minus 354 ft. or 146 ft.

It will be convenient to lay out the curve by offsets



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70 ft. apart. By the formulae, $p = R - \sqrt{R^2 - l^2}$, we have: $p = 500 - \sqrt{250000 - 4900} = 4' 11''$; $p = 500 - \sqrt{250000 - 19600} = 20' 0''$; $p = 500 - \sqrt{250000 - 44100} = 46' 3''$; $p = 500 - \sqrt{250000 - 78400} = 85' 9''$; $p =$, by preceding process, $146' 0''$.

These may be laid off from the main track by squaring carefully with the 3-4-5 triangle method. The siding tangent may then be produced backward by the aid of the string. The point of tangent, which is the beginning of the back measurements, will be 500 ft. from the main track. The above distances may then be laid off in the same order, and the curve will be fully established. The length measured around the curve through the stakes will be a few inches less than 393 ft., which is the exact length of the curve.

Problem 3—The problem when the line of the siding either converges toward or diverges from the line of the main track may appear to be quite complicated, but when understood becomes fairly simple. The field work necessary for the solution of such a case consists only in measuring the angle of divergence and the offset distance at the point of tangency. The problem then is to determine the position of a tangent parallel with the main track, which will make the curve with the chosen radius pass through the point desired, and be tangent to the line of the siding at that point.

The field books develop, with great interest to the mathematically inclined, the problem of finding the equal radii for a known position of the line joining

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the two ends of the reversed curve. But as the effect of such a proposition is to establish a curvature that will generally necessitate the use of special frogs it is clearly not of much use in the solution of the practical track problem.

The angle may be obtained with the tape line by laying down equal distances along the two sides of the angle and measuring the spread at the ends of such distance, (care being taken that the measurement is along a broken line as previously explained), and by dividing the constant 57.3 by the ratio of these measurements, which, it will be noted, is the same problem as used in measuring the angle of a frog.

The length of chord subtending a central angle of this computed value may be found with sufficient accuracy by dividing the angle by the degree of curve. The tangent offset for this chord will be obtained from the formulae in Problem 1, and the linear distance by a solution of the right-angled triangle in which the chord is the known hypotenuse and the tangent offset the other known side. The position of the parallel tangent, and the linear distance to the point of curve, are now known and the solution of the problem becomes simply that of Problem 1, except that for the diverging line a portion of the computed curve is imaginary, and for the converging line a portion of computed curve will be duplicated beyond the point of tangency with the imaginary parallel line.

44. PROBLEMS IN INSTRUMENTAL LAYOUT.

Problems 4 and 5—The problem of establishing a connection from curved main track requires instrumental work in measuring the angle between the siding tangent and the tangent to the main track curve at the point of intersection and of deflecting for the several stations, after computing the length of curve between the point of intersection and the P. C. of the siding curve and the distance on the siding tangent between the main track curve and the P. T. of the siding curve. The distance from the main track curve to a possible point of tangent for the siding curve should be measured as a check on the selection of radius for the siding curve. The choice of curves is limited to those which will permit of the use of a regular number of frog and will thus be the degree of curve of some regular connection plus or minus the degree of the main track curve, depending upon whether the siding is from the inside or outside of the curve.

There are six cases of this one general problem of which two that most commonly occur are given. The other cases include two more from the outside, in both of which Δ is greater than 90 degrees and R^1 either greater or less than $R \cos \Delta$, and two more from the inside in both of which Δ is less than 90 degrees and R^1 either greater or less than $R \cos \Delta$. Each case supplies variations which the mathematical skill of the engineer will readily differentiate.

The solution of all is rendered more facile by ex-

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solution indicated for the two cases may be applied with apparent modification to all the cases, when the angle between the siding tangent and the radii passing through the P. C. of the siding curve may be ob-

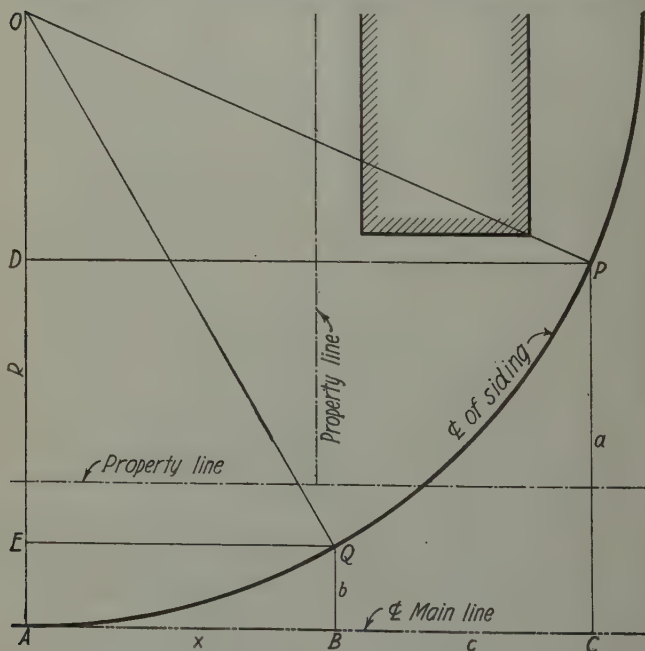


Fig. 21. Problem 6, Instrumental Layouts.

tained, as well as the central angle of the siding curve, and the distance to the actual P. T. of the siding curve, when a test of the correctness of the assumed radius will be had upon comparison with the tentative measured distance.

When it is not necessary to immediately establish the siding curve, the work may be greatly simplified by taking scale measurements from an accurately plotted plan, and these will answer every purpose if the original survey was correct and the drawing made to a scale as large as 1 in. to 40 ft., or preferably 1 in. to 32 ft.

45. PROBLEM OF 2-POINT COINCIDENCE.

Problem 6—The problem of locating a siding on a continuous simple curve which shall pass through two definite points is of very frequent occurrence, as when a property corner must be avoided and farther on a corner of a building cleared. The finite problem is capable only of theoretical solution, when the result will be a curve which may or may not approximate that of some regular connection, but it will generally be possible to change one or both points so that the curve of the nearest regular number of frog may be employed.

The theoretical solution is readily made by means of the geometrical relations indicated in the diagram and furnishes the two following formulae by which the radius may first be computed and if this answers the practical requirement, the distance from the point of curve to the foot of the perpendicular through the nearer point.

It will be noted that the formula for obtaining the radius has been reduced with a view of establishing the function R in its simplest form, which will be found to facilitate greatly the detailed solution. In-

deed, without this simplification the solution is immeasurably tedious.

$$R = \frac{a+b}{2} - \frac{c^2}{2(a-b)} = \frac{c}{a-b} \sqrt{2bR-b^2}$$

$x = \sqrt{b(2R-b)}$

The factor preceding the square root sign need only be carried to two decimal places, and to the same degree of accuracy when squared. The remaining members may be used throughout of the nearest even whole number.

When the radius found is not of practical application, as when a radius of 375 ft. results which lies midway between the curve of a No. 6 and of a No. 8, No. 7 not being used, the problem becomes one of adjustment within the limits that are possible for changes in the two assumed points. The quarters will seldom be so close that a change of a few feet will not be practicable and in such event the choice will lie between a compounded curve and a special frog.

A solution of the extreme case mentioned will afford some hints that will tend to simplify the solutions of other problems. It should be noted that a radius within 50 ft. will furnish practical results in the use of any particular frog. Thus a radius of 300 ft. will answer for a No. 6 or 450 ft. for a No. 8, but, upon the determination of the radius, the distance should be computed to the point where the offset distance is equal to the gage plus $\frac{1}{2}$ in. and this point used for the point of frog, and a proper lead laid off to determine the point of switch which need not be exactly at the point of curve.

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Let $a = 137$, $b = 51$, $c = 100$; then, $R - 152 = 1.16\sqrt{102R - 2,601}$
 $R^2 - 304R + 23,104 = 138R - 3,511$
(138) (25,737)

$$R^2 - 442R + 48,841 = 22,226$$

$$(diff. 25,737)$$

$$R - 221 = 149, \text{ or } R = 370.$$

Changing to $a = 1.32$, $b = 56$, $c = 100$, $R - 160 =$
1.32 $\sqrt{112R - 3,136}$

$$R^2 - 320R + 25,600 = 196R - 5,456$$
(196) (40,904)

$$R^2 - 516R + 66,564 = 35,508$$

$$(diff. 40,964)$$

$$R - 258 = 189, \text{ or, } R = 447 \text{ ft., which permits the use of}$$

No. 8.

Changing to $a = 144$, $b = 44$, $c = 100$, $R - 144 = \sqrt{88R - 1,936}$
 $R^2 - 288R + 20,736 = 88R - 1,936$
(88) (14,608)

$$R^2 - 376R + 35,344 = 12,672$$

$$(diff. 14,608)$$

$$R - 188 = 113, \text{ or } R = 301 \text{ ft., which permits the use of}$$

No. 6.

46. PRACTICAL CONSIDERATIONS IN SIDING LAYOUT.

Clearance—The feature of clearance in siding layout is a basic one because it concerns not only the movement but affects also the question of safety to persons. Some roads prescribe the minimum distance from the track for structures and a few require that this limit shall be followed in the case of movable obstructions. But the addition to this minimum made necessary by the nosing, overhang or tilt of the cars, which is a variable one, is not generally stated. Assuming that the widest car which moves in regular

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traffic is 10 ft. 9 in., a limit of 4 ft. 7 in. from the gage line of tangents for all obstructions would allow a margin of 1 ft. 7 in. without any correction for accidental unevenness of elevation or for swaying of the car while in motion and with a fair degree of maintenance this would render the operation entirely safe.

Car design is such that in a general way the nosing nearly equals the overhang on curves that are without superelevation. The corrections may be readily computed for cars with 30-ft. truck centers by taking one-fourth the degree of the curve as inches off overhang, and assuming that the nosing is no more than that figure, and adding or subtracting whatever may be proper for the superelevation employed. If this is $1\frac{1}{2}$ in. as suggested farther on, the tilt at the eaves of box cars would add or subtract $4\frac{1}{2}$ in. from the correction as the low or high side were in question; but for vertical obstructions the correction on the high side would be $1\frac{1}{2}$ in. at the hand hold.

The overhead clearance limit is conveniently fixed at 16 ft. above the top of rail, which meets the requirements of all present equipment and probably is ample for all future design. As this clearance will not pass a man riding a car, tell-tales should be placed. The least overhead clearance that will safely pass trainmen standing upon the highest cars is 20 ft. 9 in. above the top of rail.

The fact should not be overlooked that at the end of the curve a correction should also be made which

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is one-half that for the body of the curve. The distance beyond the point of tangent to the point where correction no longer applies is about 18 feet.

Alinement—The considerations of alinement, grade and superelevation are other important elements in a siding layout. As a general proposition if space is available, no shorter radius should be employed than can be operated practically by any class of engine. For most roads this is the curve of a No. 6 turnout from tangent which is 23 deg. or 250 ft. radius. This requirement is not practical in congested districts, and it will often be necessary to modify the curvature to just what a due consideration for safety in coupling cars will permit. This radius has been variously determined, but probably is close to that of a No. 5 turnout from tangent or a 162-ft. radius. Where sharp curvature and maximum gradient are both involved, insistence should be had upon the best possible feature for each.

Gradient—The allowable maximum gradient for siding connection for the best service is 2 ft. in 100 ft., and the maximum for track upon which cars stand for unloading 1 ft. in 100 ft. It is possible to operate sidings with a gradient of as much as 4.7 ft. in 100 ft., but the best drill engines cannot handle more than three loaded cars on such a gradient and the operation is therefore unprofitable. The danger of wrecks from cars running away, with the possibility of fouling the main line even when derails are provided, renders such a gradient highly objectionable. It is very

important that all radical changes of grade in siding connections shall be eased by vertical curves, as the absence of such advantage is a frequent source of accident.

The general feature of gradient concerns the approaches to coal trestles more particularly, and is one where the road must often take a firm stand against the insistence of the applicant for greater headroom. The adoption of a limiting gradient by the road many times would supply the means of combating such demands. If more headroom is required it can nearly always be had by excavating the site. Any less clear height than 6 ft. 6 in. below the stringers will not permit of a horse being driven through and any greater headroom than 14 ft. will break the coal or grind a measurable amount of it into dust with a considerable loss to the dealer.

Superelevation—The question of superelevation is one concerning which authorities differ. It will be argued that no superelevation is possible through the connection and therefore none is necessary beyond the connection. But the difference is that the track through the extent of the switch timbers is more rigidly secured in line and surface, and gage as well, if tieplates be used on the timbers, and there is less chance for distortion. It will be found that a superelevation of $1\frac{1}{2}$ in. for all siding curves is a decided maintenance advantage.

Maintenance—The importance of good line and surface is not fully appreciated. In very many obscure

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cases of siding derailment, wherein the cause is given as "truck failing to curve," it is really irregular line or uneven elevation. The matter of run-off of the superelevation is a vital one in modern operation. To safely pass all types of equipment the run-off should not be made at a greater rate than 1 in. to 33 ft. If through poor maintenance the rate should become greater than $1\frac{1}{2}$ in. to 33 ft., derailment would be likely to result.

To spend money in siding maintenance is much better than spending it for small wrecking, with its annoying interruption to drill work or the possibility of injury to men. The best maintenance of sidings can only be attained by constant inspection and supervision. The trackwalker should go over every siding once every day. The foreman should inspect each siding in his territory twice a week. The supervisor should make a careful examination of his sidings and switches once every month and make permanent notes of what he finds. He should also require a report every two weeks from his foreman stating that he has made his inspections and calling attention to any specified repairs that may be necessary requiring material that he lacks. For the best results the foreman should not be overburdened with siding responsibility. Probably 30 siding switches are the most that one foreman can look after if he has main track duties also.

CHAPTER XIV.

SPECIAL PRACTICES.

Staggered-Point Switches—Considerable economy is effected in the wear of switch points in yards at places where the service is extreme, by moving the point of lesser wear back a distance of 26 in., so that the first lug of the one point and the second lug of the other are opposite; and by adding a guard rail 9 or 10 ft. long curved sharply through 12 in. at the end nearest the switch and in the standard manner at the other end. The guard rail is set close to the switch, which permits 12 in. of 2-in. flangeway opposite the point receiving the greatest lateral thrust from the traffic loads.

This greatly increases the life of the point and is an excellent protection against derailment as well. The two opposite lugs must be connected with the standard head rod, and for entire safety each lug should be connected with the one diagonally opposite. If made on a standard plan these rods may be of regulation design, but if resort must be had to make-shift design, a flat rod of $2\frac{1}{2}$ in. by $\frac{3}{4}$ in. material is quite satisfactory. Care should be taken that the heel gage of the shortened point is widened to maintain proper gage. As the guard rail is subjected to a severe strain it should be braced by anchor clamps and at least one tie plate guard rail fastener.

This arrangement has been used in a number of

SPECIAL PRACTICES

locations where the service is extreme, but the saving at one point will serve for illustration. Two switches follow each other closely and spring from the inside of a 17 deg. curve. Approximately 30 movements are made over the switches every day. At each one of the switches the high side point of new 100-lb. material formerly lasted just two months, it being a matter of actual knowledge that 12 switch points were consumed at the two places in one year. Besides, it was the rule for a derailment to herald the

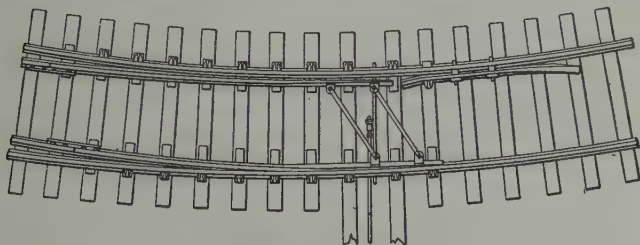


Fig. 22. Staggered Switch Points.

time for renewal of the worn points. Since the points have been protected by this method they have lasted fully five years. Sixty switch points are thus saved in this period and derailments have also been eliminated.

It is doubtful if any other device or method in switch work is capable of effecting one-tenth the saving in expense for maintenance as the one described.

Making a Crossing with Switch Points—The sketch illustrates a means of effecting a crossing by the use of switch points. It is plain that the points

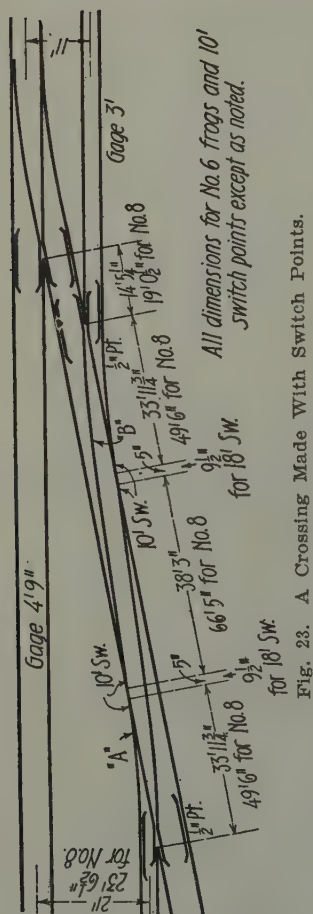


Fig. 23. A Crossing Made With Switch Points.

merely serve the purpose of movable point frogs. A narrow-gage track is shown intersecting a standard-gage track, because that is probably the principal combination likely to occur. Each switch point may be thrown by an independent lever, or they can all be pipe-connected and thrown by one operation. The points composing each separate frog are placed a distance apart in inches equal to one-fourth the ratio between the length of the point and the heel gage, for points $\frac{1}{8}$ in. thick at the point of switch, or $\frac{1}{2}$ the ratio for points $\frac{1}{4}$ in. thick. For a straight crossing the distance between the heels of the end switches is equal to the difference of the gages plus twice

the heel gage multiplied by the tangent of the switch angle.

Shifting Connections Endwise—When it becomes

necessary to move a connection or crossover to a new location within certain limits there are usually two alternatives, viz., to build a new connection or to shift the old one by mechanical means. When the distance to be moved is less than 100 ft. it will generally be preferable to move it bodily, especially if a locomotive or steam derrick pull is possible. The joints at the ends of the connection are broken, all ballast is cleaned from the cribs, and a flat bed level with the bottom of tie prepared at the new location. The ties about the switch are apt to give trouble, but this may be overcome by spiking them in place beforehand. A connection may thus be moved by a large force of men with bars. The saving in expense by shifting rather than rebuilding is quite considerable.

Renewing Slip Switches with Steam Derrick—When the old material in a slip that is in service is considerably worn it is hardly safe to attempt to renew the slip piecemeal. The difficulty of properly compromising the old work with the new is practically prohibitive. There are few points where the main track and the slip can both be dispensed with while a new set is being installed. It has become a nearly standard practice to rebuild the slip complete beside the tracks, and, at a convenient time between regular trains, set it in place with steam derricks or cranes, holding it by each end. If the slip is larger than No. 8 it will be necessary to furnish longitudinal reinforcement. It is quite important to provide a margin of 1 in. at each end for the joining of the rails. A

SIMPLIFIED CURVE AND SWITCH WORK

No. 8 slip may be thus renewed in as short a time as 15 minutes.

Avoiding a Facing Point Switch—The problem of avoiding a facing point switch usually is solved by building a parallel siding on regular track centers with the main track, and turning the spur from such siding. If a bridge or other structure prohibits the placing of the siding in this manner it may be laid as a gauntlet with the main track.

The main point to be observed is that the gauntlet distance shall be such as to employ for the crossing of the spur with the first rail the next larger frog to the one used for crossing the second rail. It is also an advantage to separate the $\frac{1}{2}$ in. points a distance equal to the length of the frogs. With a No. 8 and No. 10 frog the gauntlet distance would be 20 in.; with a No. 6 and No. 8 frog it would be 26 in. When the distance is over 10 in. the ties should be relined.

Advancing the Point of Switch—It is sometimes impracticable to place a switch at the point required by the adopted location of the frog. An existing structure may prevent it, or the need of drawing the switch closer to the power system may be imperative. The solution of such a case is to employ as long a switch as possible and extend the switch tangent to a point where a regular curve will connect with the frog tangent.

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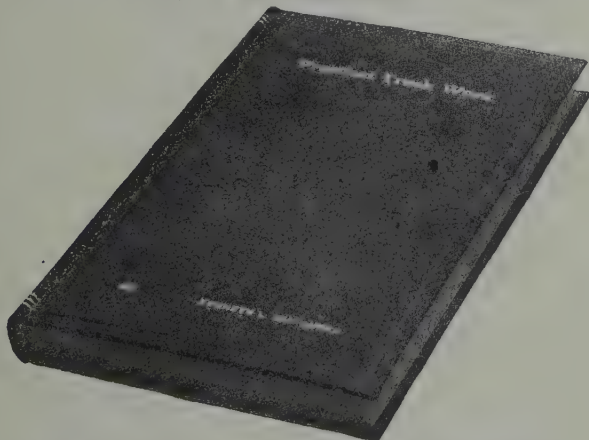
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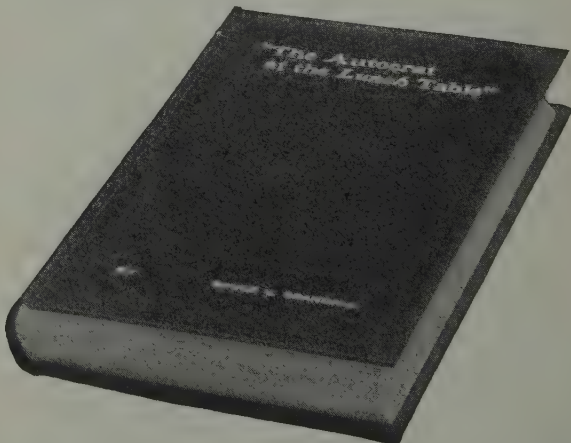
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